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Blanch Frisé
Slater High School

FIRST BOOK

IN

NATURAL PHILOSOPHY

FOR THE USE OF

Schools and Academies.

BY

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PREFACE.

THE authors have endeavored to present in this little book a brief, simple, and accurate statement of those facts and principles of natural philosophy with which every one ought to be familiar, and which may at the same time serve as a foundation for a more extended course, in case the student has time and inclination to pursue the subject further. They have thus sought to make the book really what it claims to be in name, — a first book in natural philosophy.

Great pains have been taken in the selection and arrangement of topics, and in giving due prominence to each. In order to make the book sufficiently brief, and at the same time to do justice to the recent remarkable advancement in our knowledge of the forces of Nature and in their practical application, it has been necessary to omit certain illustrative matter which some teachers will be likely to miss. We believe, however, that the illustrations and experiments given are all that are needed to make the text clear. Others can of course be added by the teacher, according to the condition of his pupils and the supply of apparatus at his disposal;

and they will come from his lips with a force which no printed statement can give them. Our experience has been, that one of the best methods of reviewing a subject in natural philosophy is to illustrate it by some experiment not given in the book, and then to question the pupils upon it. A few familiar examples of such experiments are given in an appendix.

The subject has been carefully divided into topics, and these subdivided into chapters and sections. Each chapter closes with questions, calculated to test the pupil's knowledge of its contents.

The greatest care has been taken with the cuts designed to illustrate the text; and it is believed that they will compare favorably with those in any similar text-book yet published. Many of the cuts are from the French edition of Ganot's "Elementary Physics."

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FIRST BOOK IN NATURAL PHILOSOPHY.

I.

MATTER, FORCE, AND MOTION.

CHAPTER I.

MATTER.

1. **The Senses.** — We have five *senses* by which we perceive objects about us; namely, *sight*, *hearing*, *touch*, *taste*, and *smell*. It is by means of these senses that we obtain all our knowledge of the world around us.

2. **Matter.** — Every thing that occupies space, and is capable of being perceived by our senses, is composed of *matter*.

Matter may be defined as that which occupies space, and is capable of being perceived by the senses.

A *body* is a distinct portion of matter. This term is usually applied only to those portions of matter which have a sensible size.

The different kinds of matter are called *substances*.

Illustrations. — Iron is a substance; and a separate piece of iron is a body. Wood is also a substance; while any limited portion of wood, as a log, a board, a box, or a table, is a body.

Sometimes matter is in such a position, or in such a condition, that we can perceive it only by one of our senses. In other cases we can perceive the same matter by two or more of our senses at once.

Illustrations. — A star, owing to its distance, can be perceived only by the sense of sight. A distant bell can be perceived only by the sense of hearing. The air is composed of matter in such a state that it can be perceived only by the sense of touch, as when the air is blown against our hands and face, or when we move our hand rapidly to and fro in the air. We may perceive a rose which we hold in our hand, by the sense of sight, of touch, and of smell at one and the same time. An apple held in the hand may be perceived by the sense of sight, of touch, of smell, and of taste.

3. **The Dimensions of Matter.** — Since matter occupies space, it must have three dimensions; namely, *length*, *breadth*, and *thickness*.

4. **English Units of Length.** — We measure length in inches, feet, yards, and miles. These are called the *English units of length.* It takes twelve inches to make a foot, three feet to make a yard, and 1760 yards, or 5280 feet, to make a mile. The inch is usually divided into halves, quarters, eighths, sixteenths, and thirty-secondths, each division being one-half of the next larger. Sometimes the inch is divided into tenths.

5. **French Units of Length.** — In France lengths are usually measured in *meters*, and in fractions or

multiples of the meter. The fractions of the meter are the *decimeter*, or the tenth of the meter; the *centimeter*, or the hundredth of the meter; and the *millimeter*, or the thousandth of the meter. The multiples of the meter are the *decameter*, or ten meters; the *hectometer*, or one hundred meters; and the *kilometer*, or one thousand meters. The French units of length in most common use are the *centimeter*, the *meter*, and the *kilometer*.

The meter is nearly forty inches (39.37 inches) long, the decimeter is about four inches long, the centimetre about four-tenths or two-fifths of an inch long, and the millimeter about four one-hundredths or one twenty-fifth of an inch long. The kilometer is about five-eighths of a mile.

6. **Units of Surface.** — The units in which surfaces are measured are the *squares* of the units of length.

The *English* units of surface are the *square inch*, the *square foot*, the *square yard*, and the *square mile*. There are 144 square inches in a square foot, and nine square feet, or 1296 square inches, in a square yard.

The *French* units of surface are the *square meter*, the *square decimeter*, the *square centimeter*, etc. There are about 1550 square inches in a square meter.

7. **Units of Volume.** — By the *volume* of a body we mean the space which it occupies. The units of volume are the *cubes* of the units of length.

The *English* units of volume are the *cubic inch*, the *cubic foot*, the *cubic yard*, etc. There are 1728

cubic inches in a cubic foot, and 27 cubic feet in a cubic yard.

The *French* units of volume are the *cubic meter*, the *cubic decimeter*, the *cubic centimeter*, etc. The cubic meter is equal to nearly thirty-six cubic feet. The cubic decimeter is called a *liter*. The liter is equal to about one pint and three-fourths.

8. **Mass.** — By the *mass* of a body we mean the quantity of matter in it. Bodies which have the same volume often have very different masses. Thus a cubic inch of cork has the same volume as a cubic inch of lead; but the cubic inch of lead has a much greater mass than the cubic inch of cork, the lead being much more compact, or *dense*, than the cork.

9. **Units of Mass.** — We measure mass in *pounds*, *ounces*, and *grains*. It takes sixteen ounces, or seven thousand grains, to make a pound. A pound is simply an amount of matter equal to that in a certain piece of platinum preserved by the government as a standard.

The *French* unit of mass is called the *gram*. It is the amount of matter in a cubic centimeter of water at a temperature of thirty-nine degrees. A cubic centimeter of water is a little cube of water which measures about two-fifths of an inch each way. The gram is equal to about fifteen grains. There are about four hundred and sixty grams in a pound. The subdivisions of the gram are the *decigram*, the *centigram*, and the *milligram*. These are respectively the tenth, the hundredth, and the thousandth of a gram. The multiples of the

gram are the *decagram*, the *hectogram*, and the *kilogram*. These are respectively ten, a hundred, and a thousand grams. A kilogram is nearly two pounds and a quarter.

NOTE. — In scientific books the *French* forms, *metre*, *decimetre*, *gramme*, *kilogramme*, *litre*, etc., are often used instead of the *English* forms given above. *Decameter*, *hectogram*, etc., are sometimes spelled *dekameter*, *hektogram*, etc.

QUESTIONS.

1. How many senses have we? 2. Name them. 3. What do we do by our senses? 4. What do we obtain by means of them? 5. What is matter? 6. What is meant by a body? 7. Give illustrations. 8. Give illustrations of matter so situated that we can perceive it by one of our senses only. 9. Give an illustration of matter which exists in such a condition that we can perceive it by one sense only. 10. Give illustrations of matter which may be perceived by several of the senses at the same time. 11. How many dimensions has matter? 12. Name them. 13. Name the English units by which length is measured. 14. How many inches in a foot? 15. How many feet in a yard? 16. How many inches in a yard? 17. How many yards in a mile? 18. How many feet in a mile? 19. What are the usual subdivisions of the inch? 20. What is the French unit of length? 21. Give the subdivisions and multiples of this unit. 22. About how many inches in a meter? 23. In a decimeter? 24. In a centimeter? 25. In a millimeter? 26. What is about the length of a kilometer? 27. What is the exact length of the meter? 28. What are units of surface? 29. Name the chief English units of surface. 30. Name the chief French units of surface. 31. How many square inches in a square foot? 32. How many square feet in a square yard? 33. How many square inches in a square yard? 34. How many square inches in a square meter? 35. What are units of volume? 36. What is meant by the volume of a body? 37. Name the chief English units of volume.

38. Name the chief French units of volume. 39. How many cubic inches in a cubic foot? 40. How many cubic feet in a cubic yard? 41. How many cubic feet in a cubic meter? 42. What is the liter? 43. What is its volume in English measure? 44. What is meant by the mass of a body? 45. What is the difference between mass and volume? 46. Do bodies of the same volume always have the same mass? 47. Give an illustration. 48. Name the English units of mass. 49. How many ounces in a pound? 50. How many grains in a pound? 51. What is the pound? 52. What is the name of the French unit of mass? 53. What is it? 54. About how many grains in the gram? 55. Name the subdivisions and the multiples of the gram. 56. How many pounds in a kilogram?

CHAPTER II.

THE STRUCTURE OF MATTER.

10. **The Material Universe.** — All the matter in existence constitutes what is called the *material universe.*

11. **The Structure of the Material Universe.** — The material universe is not a continuous mass of matter, but is composed of bodies like the earth, the moon, the sun, and the stars; and these bodies, instead of being in contact, are very far apart. They are not scattered at random through space, but are grouped together in various ways so as to form *systems* of bodies.

The sun is accompanied by a number of bodies similar to the earth, which are called *planets.* The five planets, which, next to the earth, are best known, are *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn.* These planets all *revolve* around the sun; that

is to say, they move around the sun in paths, or *orbits*, which are of a circular form. The earth moves in her orbit at the rate of eighteen miles a second; Mercury, at the rate of nearly thirty miles a second; and Saturn, the slowest of the planets named, at the rate of about six miles a second. An express train at its fastest goes about a mile a minute. The earth is travelling in her orbit at the rate of more than *a thousand miles* a minute. An express train moving as fast as the earth would go from New York to Chicago in about one minute, from Chicago to San Francisco in about two minutes, and around the globe in twenty-five minutes.

Many of the planets are accompanied by *moons*. The earth has one moon, Mars has two moons, Jupiter five, and Saturn eight. Mercury and Venus are without moons. The moons revolve around their planets, and always keep with them in their revolutions around the sun. A planet and its moons constitute a group of bodies called a *planetary system*.

The sun is moving through space at the rate of about two hundred and fifty miles a minute, or about one-fourth as fast as the earth is moving around the sun. The planets which revolve around the sun always keep with him in his journey through space. The sun and planets constitute a group of bodies called a *solar system*. A solar system is thus seen to be made up of single planets and of planetary systems. The structure of our solar system as described above is shown in Figure 1.

Fig. 1.

Our sun is simply one of the *stars;* and, at the distance of the other stars, it would appear smaller than many of them. Each star is probably the centre of a solar system similar to our own. These solar systems, singly and in groups, make up the *stellar universe;* just as the planets, singly and in groups, make up the solar system.

12. **The Dimensions of the Stellar Universe.** — We have seen that a body moving with the speed of the earth in its orbit would go around the globe in twenty-five minutes. Light travels at the rate of nearly a hundred and ninety thousand miles a second, or fast enough to go around the world more than seven times in a second. It would take light about one second and a fourth to go from the earth to the moon, about eight minutes to go from the earth to the sun, and about three years and a half to go from the sun to the nearest star. We thus gain some faint notion of the distance which separates moon from planet, planet from sun, and sun from star.

13. **Molar Motion.** — The motion *of visible bodies* is called *molar* motion.

Illustrations. — We have examples of molar motion in the fall of a stone, in the flight of a bird, in the sailing of a ship, and in all the motion of bodies at the surface of the earth. The grandest examples of molar motion are exhibited in the stellar universe. The moons are at one and the same time moving in their orbits around their planets, with their planets around the sun, and with the sun through space.

Every body in the universe of which we have any knowledge is in motion, and very many bodies

share several very rapid motions at one and the same time.

14. **Rest.** — Bodies are said to be *at rest* when they are not changing their positions with respect to other bodies around them, even though they are really moving very rapidly.

Illustrations. — A body lying on the deck of a steamer is said to be at rest, because it keeps in the same position with respect to other objects on the steamer. It may, however, be moving forward very rapidly with the steamer through the water. A body lying on the ground is said to be at rest, because it keeps in the same position with reference to surrounding points on the earth's surface; but it is really moving forward very rapidly with the earth through space.

15. **The Structure of Bodies.** — The structure of a body is now generally held to be similar to that of the stellar universe. A body is not a continuous, uninterrupted mass of matter, but is made up of a number of very minute and distinct particles, called *atoms*. These atoms are arranged, in various ways, into groups, called *molecules*. The atoms correspond to the sun, moon, and planets, and the molecules to the solar systems. A body is made up of these molecules in the same way that the stellar universe is made up of solar systems. The spaces between the atoms and molecules within a body are probably as great, compared with the size of the atoms and molecules, as are the spaces between the planets, sun, and stars, compared with the size of these bodies. If a being were living on one of the atoms within a body, as small compared with the atom as we are compared with the

earth, the atoms and molecules about him, were they visible, would appear as far off to him as the sun, moon, planets, and stars do to us.

16. **The Dimensions of the Atoms and Molecules.** — No microscope has ever yet been constructed powerful enough to enable us to see the spaces between the molecules, much less the molecules themselves and the atoms of which they are composed.

Illustrations. — It has been estimated, that were a drop of water enlarged to the size of the earth, all its molecules being enlarged in the same proportion, the molecules would be about as large as billiard-balls; that is to say, a molecule of water is as small, in comparison with a billiard-ball, as a drop of water in comparison with the earth. It is supposed that there are at least three hundred quintillions of molecules in one cubic inch of air, — a number which would be represented by three followed by twenty ciphers. At the same time it is believed that the molecules themselves occupy only one three-thousandth of the space in the cubic inch. The atoms that make up the molecules are also believed to be very far apart compared with their size. We thus gain some notion of the extreme fineness of the atomic dust of which matter is composed.

17. **Molecular Motion.** — The atoms and molecules of a body are *in incessant motion*, as well as the planets and the solar systems. The atoms are all the time moving to and fro within the molecules, and the molecules to and fro within the body. The motions of the atoms and molecules within a body are called *molecular motions*.

18. **The Ether.** — All the spaces between moons, planets, and stars in the stellar universe, and all the spaces among the atoms and molecules of a

body, are supposed to be filled with a very fine and delicate material called the *ether*.

Illustrations. — Fill a glass vessel with a mixture of shot and marbles, and then pour into it all the water it will hold. The water will completely fill all the spaces among the shot and marbles. All the atoms and molecules of matter are immersed in the ethereal ocean in the same way that the shot and marbles are immersed in the water. Of course the atoms and molecules are comparatively much farther apart than the shot and marbles.

19. **Porosity of Matter.** — All substances are *porous;* that is to say, in every part of them there are spaces which are not occupied with material particles. When these spaces are large enough to be seen, they are called *visible* pores; and, when they are too small to be seen even with a microscope, they are called *physical* pores.

Illustrations. — A piece of wood is full of visible pores. Pour a little quicksilver upon a piece of chamois-skin, and gather up the skin so as to form a kind of bag enclosing the mercury. On squeezing this bag you will see the quicksilver running through the pores of the skin in a number of fine streams. In 1661 some learned men in Florence filled a thin hollow globe of gold with water, and, after closing the opening perfectly tight, they subjected the globe to great pressure. The water came through the pores of the gold, and wet the outside of the globe.

20. **Compressibility of Matter.** — A body is said to be *compressed* when it is made to occupy less space. All substances are compressible. When a body is compressed, its molecules are brought nearer together.

Illustrations. — Hold a glass goblet mouth downward, and force it down into water. The water will rise a little way into the goblet, the air inside becoming more and more compressed as the vessel is forced down.

21. **Impenetrability of Matter.** — When we say that matter is *impenetrable,* we mean that no two portions of matter can occupy the same space at the same time. All substances are impenetrable.

Illustrations. — Fill a goblet to the brim with water, and drop a marble into it. Some of the water will overflow. The marble can enter the goblet only by displacing a bulk of water equal to its own. When we pushed the inverted goblet down into water, the liquid rose only a little way into it, because the goblet was already filled with air. The water rose a little way because the air was compressed. When we pour water into an upright goblet, the air is displaced as rapidly as the water enters. Water cannot be poured into a fine tube which is closed at the bottom, because there is not sufficient room for the water to enter and the air to escape at the same time.

Strictly speaking, it is only the atoms of matter that are impenetrable. In certain cases, the molecules of one substance may work their way in among those of another, and occupy the space between those molecules. Also, in certain cases, the atoms of one substance may be introduced into the spaces between the atoms in the molecules of another substance.

22. **Divisibility of Matter.** — We may divide and subdivide any body, as a piece of wood, into smaller and smaller pieces, until these become too small to be seen with the unaided eye; and then, with the microscope, we may continue the division till the pieces are too small to be seen with the microscope.

Were the microscope powerful enough, we might go on dividing the body until we reached the molecules. During all this time the *substance* of all these pieces would remain exactly the same as that of the original body. Were the microscope powerful enough, and the instrument at our disposal delicate enough, to enable us to divide the *molecules*, the original substance would be destroyed, and we should obtain new substances.

By certain processes we may separate a substance into its molecules, and break up the molecules themselves into their atoms; but we have found no means of dividing an atom.

Illustrations. — When water evaporates, it is resolved into its molecules, which then fly about loosely in the air. When the vapor of water is heated to a very high temperature, the molecules themselves are broken up into their atoms; and, as there are two kinds of atoms in the molecules of water, we obtain two new substances, called *hydrogen* and *oxygen*.

23. **Indestructibility of Matter.** — Matter may be made to assume a great variety of forms; but no portion of matter can be blotted out of existence except by the power which created it. Bodies may be crushed into the finest powder so as to destroy their form, and their molecules may be broken up so as to destroy their substance; but the atoms are indestructible by any means known to us.

QUESTIONS.

1. What is meant by the material universe? 2. Of what is this universe composed? 3. How are the bodies which compose the material universe arranged? 4. By what is the sun

accompanied? 5. Name the five principal planets. 6. What motion have the planets? 7. How fast do the earth, Mercury, and Saturn move in their orbits? 8. How does the earth's speed compare with that of an express train? 9. By what are many of the planets accompanied? 10. Which planets have moons? 11. How many moons has each? 12. Which planets are without moons? 13. What motion have the moons? 14. What constitutes a planetary system? 15. What motion has the sun? 16. What constitutes a solar system? 17. What is probably true of the stars? 18. What constitutes the stellar universe? 19. How fast does light travel? 20. How long would it take light to go from the earth to the moon? 21. From the earth to the sun? 22. From the sun to the nearest star? 23. What is meant by molar motion? 24. Give some examples of molar motion. 25. What motion have the moons? 26. What is true of every body in the universe as regards motion? 27. When is a body said to be at rest? 28. Give illustrations of bodies in motion which are said to be at rest. 29. To what is the structure of a body similar? 30. Of what are bodies made up? 31. What are molecules? 32. To what do the atoms and molecules of a body correspond? 33. What is the size of the spaces between the atoms and molecules, compared with the sizes of the atoms and molecules? 34. How far off would the surrounding atoms and molecules appear to a being small enough to live on one of the atoms? 35. Can the molecules be seen with a microscope? 36. Give the illustration of the drop of water. 37. How many molecules are there in a cubic inch of air? 38. What fraction of the space is occupied by these molecules? 39. What is meant by molecular motion? 40. Describe the motion of the atoms and molecules. 41. What is meant by the ether? 42. Give the illustration of the marbles, shot, and water. 43. What do we mean when we say that matter is porous? 44. Name and describe the two kinds of pores that are contained in bodies. 45. Give illustrations. 46. What do we mean when we say that matter is compressible? 47. What takes place when matter is compressed? 48. Give illustrations. 49. What do we mean when we say that matter is impenetrable? 50. Give

illustrations. 51. What portions of matter only are really impenetrable? 52. To what extent is matter divisible? 53. To what extent may the division of a body be carried without altering its substance? 54. Are the atoms divisible? 55. What takes place when water evaporates? 56. When the vapor of water is heated to a very high temperature? 57. What do we mean when we say that matter is indestructible? 58. What portions of matter only are indestructible?

CHAPTER III.

FORCE.

24. **Definition of Force.** — Any push or pull, of whatever origin, upon matter, is called a *force*. A pulling force is called an *attractive* force, and a pushing force a *repulsive* force. Forces always act between two portions of matter. We do not know where the force resides, but we usually speak of it as residing in the portions of matter acted upon.

Illustrations. — The action of an attractive force may be illustrated by fastening a ball to each end of a rubber cord, and then pulling the balls apart. The cord pulls upon each of the balls, and tends to draw them together. The action of a repulsive force may be illustrated by placing a ball on each side of a thick piece of rubber, and then crowding the balls together. The compressed rubber pushes upon each of the balls, and tends to drive them apart.

25. **The Three Great Forces of Nature.** — The three great forces of Nature are *gravity*, *cohesion*, and *affinity*.

Gravity is the force which holds bodies to the

earth, moons to their planets, and planets to the sun. It is an attractive force, which tends to draw bodies together, and which acts through all known distances. It is a *molar* force.

Cohesion is the force which holds together the molecules of a body. It is an attractive force, which tends to draw molecules together. It is much stronger than gravity, but it acts only through insensible distances. It is a *molecular* force.

Illustrations. — It is gravity that holds a rod of iron to the table, and cohesion that holds the rod together. It is much easier to lift the rod from the table than to pull it in two. This shows that cohesion is stronger than gravity. Were the rod once broken, so as to separate the molecules ever so little, the parts could then be separated with ease. This shows that cohesion acts only through insensible distances.

Affinity is the force that holds together the atoms in the molecules. It is a stronger force than cohesion, but it does not act through so great distances. It is an *atomic* force.

26. **Stress, Action, and Reaction.** — The whole action of a force between two portions of matter is called a *stress.* Every stress is made up of two pushes or two pulls, one upon each of the portions of matter. These are called the two *aspects* of the stress. We always think of the force as residing in the portion of matter acted upon, and speak of the two portions of matter as pushing or pulling each other. We call one of these pushes or pulls an *action,* and the other a *reaction.* Whether we call the one or the other of these the *action* depends upon the way we are looking at it.

Illustrations. — The whole pull of gravity between a stone and the earth is called a *stress*. We say that the stone and the earth pull each other. When we think of the earth as pulling the stone, we call the pull upon the stone the *action* of the earth upon the stone, and then we call the pull upon the earth the *reaction* of the stone upon the earth. When we think of the stone as pulling the earth, we call the pull upon the earth the *action* of the stone upon the earth, and then we call the pull upon the stone the *reaction* of the earth upon the stone.

When a cannon is fired, there is a repulsive force acting between the cannon and the ball. The whole action of this force is called a *stress*. When we think of the cannon as pushing the ball, we call the push upon the ball the *action* of the cannon upon the ball, and then we call the push upon the cannon the *reaction* of the ball upon the cannon. When we think of the ball as pushing the cannon, we call the push upon the cannon the *action* of the ball upon the cannon, and then we call the push upon the ball the *reaction* of the cannon upon the ball.

27. **Strain.** — When the shape or size of a body is altered under the action of a force, the body is said to be *strained*. A *strain* is any distortion, of whatever kind, which is maintained by a force. There are strains of *flexure* (bending), of *traction* (drawing out), of *torsion* (twisting), and of *compression*.

Illustrations. — When a strip of whalebone is held bent, or a watch-spring is coiled up, it is said to be *strained;* and its strain is that of *flexure*. When a piece of rubber is stretched, it is said to be *strained;* and its strain is that of *traction*. When a strip of whalebone is twisted, it is *strained;* and the strain is that of *torsion*. When air is compressed, as in the experiment of pushing an inverted goblet into water, the strain upon the air is that of *compression*.

28. **Elasticity.** — Every strained body tends to

recover its original shape or volume. This tendency of a strained body to recover itself is called *elasticity*. There are four varieties of elasticity, corresponding to the four varieties of strain; namely, elasticity of *flexure*, of *traction*, of *torsion*, and of *compression*.

Illustrations. — Bend or twist a whalebone. On releasing it, we discover its tendency to recover its original shape. So, too, on stretching and releasing a piece of rubber, we see its tendency to recover its original length. On removing an inverted goblet which has been plunged into water, we discover the tendency of the compressed air to recover its original volume.

29. **Measurement of Forces.** — A force always tends to *change the velocity* of the body on which it acts.

Illustrations. — When a stone is thrown upward, gravity makes it move slower and slower; and, when a body is falling, gravity makes it move faster and faster.

Forces are *measured*, either by comparing them with the pull of gravity, or by the change of velocity which they are capable of producing in a second.

The pull of gravity upon a mass of a pound is called a *pound;* the pull of gravity upon a mass of a grain is called a *grain;* and the pull of gravity upon a mass of a gram is called a *gram*. A force of a pound is a force equal to the pull of gravity upon a mass of a pound; and a force of a grain or a gram is a force equal to the pull of gravity upon a mass of a grain or a gram. A force of ten grains is one equal to ten times the pull of gravity upon a mass of a grain.

A force capable of changing the velocity of a

pound of mass one foot in a second — that is, to make the mass move one foot a second faster or slower — is called a *poundal* of force. A force of a poundal is nearly equal to the pull of gravity upon half an ounce.

QUESTIONS.

1. What do we mean by a force? 2. Name the two kinds of force. 3. Give an illustration of each. 4. Name the three great forces of Nature. 5. Give an account of gravity. 6. Of cohesion. 7. Of affinity. 8. What do we mean by a stress? 9. What two aspects has every stress? 10. Where do we always think of the force as residing? 11. What names do we give to the two aspects of a stress? 12. Illustrate the use of these terms in the case of gravity acting between the earth and a stone. 13. In the case of a cannon. 14. When is a body said to be strained? 15. Define a strain. 16. Name the different kinds of strain. 17. Give an illustration of each. 18. What does every strained body tend to do? 19. What name do we give to this tendency? 20. Name the different kinds of elasticity. 21. Illustrate each. 22. What does a force always tend to do to a body? 23. What do we mean by a force of a pound? 24. Of five pounds? 25. Of a grain? 26. Of a gram? 27. Of fifteen grams? 28. What do we mean by a poundal of force? 29. It is about equal to what pull of gravity? 30. What should we mean by fifty poundals of force?

CHAPTER IV.

THE PHYSICAL SCIENCES.

30. **Phenomenon.** — Any manifestation or occurrence is called a *phenomenon.*

Illustrations. — The shining of a star, the falling of a stone and the growth of a plant, are all *phenomena.*

31. **The Physical Sciences.** — The physical sciences treat of matter and force irrespective of the phenomena of life. The chief physical sciences are *mechanics*, *astronomy*, *physics*, and *chemistry*.

32. **Material Units.** — A *material unit* is either a single mass, or else a group of masses, which keep together in their motions. The *three orders* of material units are *bodies*, *molecules*, and *atoms*. A *body* is a group of molecules which keep together in all their motions, and a *molecule* is a group of atoms which keep together in all their motions.

33. **Mechanics.** — *Mechanics* is that branch of physical science which treats of the action of force, and of the laws of motion, irrespective of any particular order of material units.

34. **Astronomy.** — *Astronomy* treats of the heavenly bodies, of gravity, by which the motion of these bodies is regulated, and of the structure of the heavens.

35. **Chemical and Physical Properties.** — The peculiarities, or *properties*, of matter which are due to the action of *affinity* and to the *atomic* structure of the molecules are called *chemical properties*. Those properties which result from the action of *cohesion* and the *molecular* structure of the body are called *physical properties*.

36. **Physical and Chemical Changes.** — Any change in matter which alters the atomic structure of the molecules, and so produces *a change of substance*, is called a *chemical change*. Any change which leaves the molecules intact, and which *does not alter the substance*, is called a *physical change*.

Illustrations. — When ice melts, or water boils, the molecular structure of the body is altered, but the molecules themselves remain intact. There is no change of substance. Melting and boiling are *physical* changes. When a piece of iron rusts, the old molecules are broken up, and new molecules are formed. There is a change of substance. The rust is a different substance from the iron. The rusting of iron is a *chemical* change.

37. **Physics.** — *Physics* treats of molecules, of the molecular structure of bodies, the motion of the molecules, the action of cohesion, and of physical properties and changes.

38. **Chemistry.** — *Chemistry* treats of the atoms, of the atomic structure of the molecules, of the action of affinity, and of chemical properties and changes.

39. **Natural Philosophy.** — *Natural Philosophy* includes mechanics and physics.

QUESTIONS.

1. What do we mean by a phenomenon? 2. Give illustrations. 3. Of what do the physical sciences treat? 4. Name the principal physical sciences. 5. What do we mean by a material unit? 6. Name the three orders of material units. 7. Of what does mechanics treat? 8. Of what does astronomy treat? 9. What do we mean by chemical properties? 10. By physical properties? 11. What do we mean by physical changes? 12. By chemical changes? 13. Give illustrations of each. 14. Of what does physics treat? 15. Of what does chemistry treat? 16. What sciences are included in natural philosophy?

CHAPTER V.

FIRST LAW OF MOTION.

40. **Velocity.** — By *velocity* we mean rate of motion. Velocity is usually stated in feet or miles per second, or in miles per hour.

Illustrations. — When we say a stone is falling with a velocity of twenty feet a second, we mean that it is moving fast enough to go twenty feet in a second. When we say that a railway train has a velocity of thirty miles an hour, we mean that the train is going fast enough to go thirty miles in an hour. When we say that the earth is moving in its orbit with a velocity of eighteen miles a second, we mean that the earth is moving fast enough to go eighteen miles in a second.

When we say a body is falling with a velocity of twenty feet a second, we mean that the body at that particular instant is moving fast enough to go twenty feet in a second. It does not follow that the body will actually go just twenty feet the next second. The body may be stopped before the end of the second; or, if it is not stopped, it will go faster and faster, and so will go more than twenty feet. When we say that a railway train has a velocity of thirty miles an hour, we mean, that, at the particular instant of which we speak, the train is going fast enough to go thirty miles in an hour. The train may go faster or slower a part of the following hour, and so actually go more or less than thirty miles.

41. **First Law of Motion.** — *A body at rest tends to remain at rest, and a body in motion tends to keep moving in the same direction and at the same rate;* that is to say, a force must act upon a body to put it in motion, or to stop a body when in motion, or to change its rate or direction of motion.

Unless acted upon by external forces, a moving

body would *always go on in a straight line and at a uniform rate.* This seems to be contradicted by common experience. All moving bodies at the surface of the earth show a decided tendency to stop. But all such bodies are acted upon by some external force acting as a *resistance.* The chief resistances to moving bodies are *friction* and *resistance of the atmosphere.*

Illustrations. — A railway train is stopped by the friction of the brakes upon the wheels, and of the wheels upon the track, and by the resistance of the air. A stone thrown upward is stopped by the resistance of the air and by the downward pull of gravity.

In proportion as the resistances are diminished, the longer will a body continue in motion: hence we may reasonably infer, that, were the resistances entirely removed, the body would keep moving on forever.

Illustrations. — A smooth stone is soon brought to rest when sliding over the surface of the earth. The same stone will slide much longer over ice, where there is less friction. A top that will spin for ten minutes in the air will spin more than half an hour in a vacuum.

42. **Inertia.** — The tendency of a body to keep at rest or in motion is called *inertia.* The greater the *mass* of a body, the greater its inertia. In order to start a body, or to stop it, or to change its rate or direction of motion, it is necessary to overcome its inertia.

Illustrations — In jumping from a carriage or car in motion, one is liable to be thrown down, owing to the tendency of the body to keep moving forward after the feet have touched the ground.

It takes *time* for a force to overcome the inertia of matter: hence, when a body receives a sudden blow, the part of the body immediately acted upon yields before there is time to overcome the inertia of the surrounding parts.

Illustrations. — If a number of checkers are piled up in a column, one of them may be knocked out by a very quick blow with a table-knife, without overturning the column. A feeble blow will fail. Stick two needles into the ends of a broom-stick, and rest the needles on two glass goblets, as shown in Figure 2. Strike the middle of the stick a quick, sharp blow

Fig. 2.

with a heavy poker. The stick will break without breaking the needles or the goblets. Here, again, a feeble or indecisive blow will fail. A soft body fired fast enough will hit as hard as lead. A tallow candle may be fired from a gun through a pine board.

43. **Centrifugal Force.** — The so-called *centrifugal force* is simply the *tendency of the parts of a rotating body to keep moving in straight lines.* This tendency increases with the speed of rotation, and sometimes to such a degree as to overcome the cohesion of the body. In this case the body will fly in pieces, as large grindstones and heavy fly-wheels have been known to do.

Illustrations. — If a stone is fastened to the end of a string, and twirled rapidly around the finger, the tendency of the stone to fly off in a straight line may become sufficient to break the string.

This tendency to move on in a straight line must be counteracted by the force acting towards the

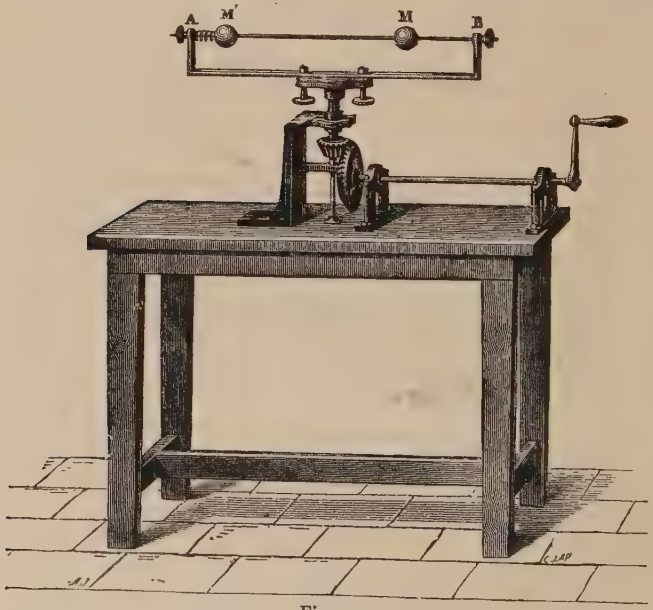


Fig. 3.

centre, in order to keep a body moving in a circle. The faster a body moves, the greater the pull needed to keep the body in its circular path. The greater the pull *upon* the body towards the centre, the greater the pull *of* the body away from the centre. The pull upon the body *towards the centre* is called the *centripetal force*, and the pull of the

body *away from the centre* is called the *centrifugal force.*

Illustrations. — The pull of a revolving body away from the centre may be illustrated by the pieces of apparatus shown in Figures 3 and 4. In the first, two balls, M and M', are placed on the rod AB, which passes through them. The rod is then put in rapid rotation by turning the crank, and the balls fly apart.

The flexible rings in Figure 4 are fastened at the bottom to the upright shaft, but are free to slide up and down upon it at the top. If these rings are whirled in place of the rod, they will become more and more flattened as the speed increases. This change of form is due to the pull of each part of the rings away from the axis. The pull will be greatest at the middle of the rings, because this part is moving fastest. It was in this way that the earth became flattened at the poles while in the fluid state.

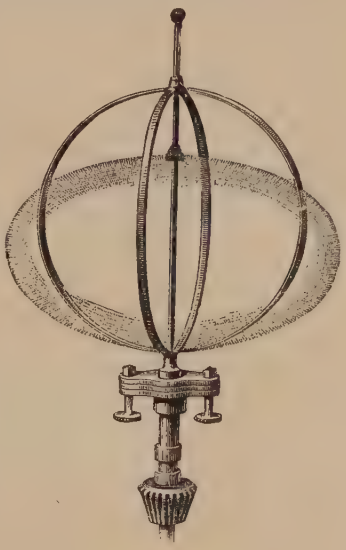


Fig. 4.

QUESTIONS.

1. What is meant by velocity? 2. Give illustrations. 3. If the velocity of a body is thirty feet a second, does it follow that the body will go thirty feet the next second? 4. Why not? 5. State the first law of motion. 6. What is needed to start a body, to stop a body, or to change its rate or direction of motion? 7. What do all moving bodies at the surface of

the earth show? 8. Why? 9. What are the chief resistances encountered by moving bodies? 10. Give illustrations of bodies stopped by resistance. 11. What is true of the motion of bodies in proportion as the resistances to their motions are removed? 12. What may we rightly infer from this? 13. Give illustrations. 14. What do we mean by the inertia of matter? 15. To what is the inertia of a body proportional? 16. It is necessary to overcome its inertia in order to do what to a body? 17. Give illustrations of inertia. 18. What is the effect of a sudden blow upon a body? 19. Why? 20. Give illustrations. 21. What do we mean by centrifugal force? 22. Give illustrations. 23. What is needed to keep a body moving in a circle? 24. What name do we give to the pull towards the centre? 25. What effect has an increase of velocity upon the centrifugal force? 26. Give the illustration of the balls. 27. Of the rings.

CHAPTER VI.

SECOND LAW OF MOTION.

44. **Impulse.** — The effect of a force in imparting motion increases with the intensity of the force and with the time during which it acts. *The product of the intensity of the force and the time during which it acts* is called the *impulse* of the force.

EXAMPLE. — The impulse of a force of fifty poundals acting twelve seconds is equal to twelve times fifty, or six hundred.

It takes the same impulse to stop a body that it does to put it in motion.

Illustration. — The greater the force with which a ball is thrown, the faster it moves, and the harder it is for the catcher to stop it. It requires the same exertion to stop the ball as it did to throw it.

45. **Momentum.** — The impulse needed to set a body in motion increases with the mass of the body and with the velocity which is imparted to it. So, also, the impulse needed to stop a body increases with the mass of the body and with its velocity. *The product of the mass of a body by its velocity* is called the *momentum* of the body.

EXAMPLE. — The momentum of a mass of eighty pounds, having a velocity of ninety feet a second, is equal to ninety times eighty, or seven hundred and twenty.

Illustrations of Momentum. — If a cannon-ball and a marble are struck equally hard with a mallet, the marble will be shot forward with a much greater velocity than the cannon-ball, but with the same momentum. It would be just as hard to stop the cannon-ball as the marble. A large ship, even though moving slowly, strikes the wharf with crushing power, owing to its great momentum. A bullet, though its mass is small, strikes with deadly effect when fired from a rifle, because its great velocity gives it a great momentum. A ship caught between two icebergs, whose motion is barely perceptible, is crushed as if it were an egg-shell, the great mass of the icebergs giving them an enormous momentum.

46. **Second Law of Motion.** — *The change of momentum of a body is equal to the impulse which produces it, and is in the direction in which the force acts.*

EXAMPLE. — The change of momentum produced by a force of eighty poundals acting five seconds would be equal to five times eighty, or four hundred.

The velocity which a force will impart to a body is directly proportional to the impulse of the force, and inversely proportional to the mass of the body; that is to say, the velocity imparted by a force is *equal to the quotient of the impulse divided by the mass.*

EXAMPLE. — A force of twelve poundals would impart in twenty seconds, to a mass of five pounds, a velocity of $240 \div 5$, or 48 feet a second.

A force has the same effect in producing motion, whether it acts upon a body at rest or in motion.

Illustrations. — A ball dropped from the ceiling of a car in motion would strike the floor in the same place and with the same velocity as if the car were at rest. The ball while falling has kept, also, the forward motion of the car. If a boy while walking throws a ball straight up into the air, he can catch it when it comes down, just as if he were standing still.

A force has the same effect in producing motion, whether it acts alone or with other forces.

Illustration. — A steamer headed directly across a river in which there is a swift current will cross the river in the same time as if there were no current. It will also be carried down stream just as far as it would have been, had it been allowed to float quietly with the current. The steam and the current each carries the boat just as far in the direction in which each acts as if acting alone.

47. **Parallelogram of Motion.** — To find the path of a body A (Figure 5) acted on by two forces at the same time, draw AB to represent the path the body would have taken, had it been acted on by the first force alone, and AC to represent the path it would have taken, had it been acted on by the other force alone. Through B draw BD parallel to AC, and through C draw CD parallel to AB, so as to complete the parallelogram $ABDC$. Draw the diagonal AD. This diagonal will represent the path taken by the body when acted upon by both forces together.

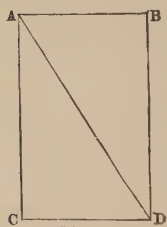


Fig. 5.

48. **Falling Bodies.** — We have illustrations of the second law of motion in the case of *falling bodies*. Were it not for the resistance of the air, gravity would increase the velocity of a falling body at the rate of about thirty-two feet a second. Starting from a state of rest, gravity would give a body a velocity of thirty-two feet during the first second. During the next second gravity will have the same effect upon the body as during the first second, although the body is already in motion, and will give it an additional velocity of thirty-two feet; and so for each succeeding second.

To find the *velocity* of a body falling from a state of rest, *multiply thirty-two by the number of seconds it has been falling.*

EXAMPLE. — The velocity of a body falling from a state of rest, were it not for the resistance of the air, would be, at the end of the eighth second, eight times thirty-two, or two hundred and fifty-six feet.

Gravity causes a body falling from a state of rest to fall sixteen feet the first second; and during each subsequent second it causes it to fall sixteen feet more than its velocity at the beginning of the second.

Illustration. — At the beginning of the second second, the velocity of a body falling from a state of rest is thirty-two feet. This velocity would of itself carry the body down thirty-two feet during this second. Gravity causes it to fall sixteen feet farther: hence it would fall $32 + 16$, or 48 feet, the second second. During the third second it will fall $64 + 16$, or 80 feet; during the fourth second it will fall $96 + 16$, or 112 feet, etc. It appears, then, that a body will fall three times as far the second second as the first, five times as far the third,

seven times as far the fourth, etc. The distance each second increases in the ratio of the odd numbers, three, five, seven, nine, etc.

49. **Rising Bodies.** — Gravity changes the velocity of a rising body thirty-two feet a second, but in this case it *retards* the body.

To find the *velocity* of a rising body at any time, *multiply thirty-two by the number of seconds it has been rising, and deduct the product from the velocity with which it started.*

EXAMPLE. — A body starts upward with a velocity of nine hundred feet a second. What would be its velocity at the end of the twentieth second? $32 \times 20 = 640$. $900 - 640 = 260$. The velocity would be two hundred and sixty feet.

Gravity would cause a rising body to rise each second sixteen feet *less* than its velocity at the beginning of the second.

EXAMPLE. — If a body started upwards with a velocity of five hundred feet, it would rise $500 - 16$, or 484 feet. Its *velocity* at the end of this second will be $500 - 32$, or 468 feet. The next second it will rise $468 - 16$, or 452 feet. The third second its velocity will be $468 - 32$, or 436 feet; and it will rise this second $436 - 16$, or 420 feet; and so on.

50. **A Body Projected Horizontally.** — Gravity would have the same effect upon a ball fired horizontally as upon one dropped from the same height. Each would strike the ground at the same time.

Illustration. — Suppose a ball fired horizontally in the direction AF (Figure 6), with a velocity which would carry it from A to F in five seconds. Divide the line AF into five equal parts, AB, BC, CD, DE, and EF. Let the vertical line AL represent the distance a body would fall from A in five seconds. Let AG represent the distance the body would fall

the first second, GH the distance it would fall the next second, HI the distance it would fall the third second, IK the distance it would fall the fourth second, and KL the distance it would fall the fifth second.

During the first second the body projected horizontally would move forward as far as from A to B, and would be pulled down by gravity from B to 1, a distance equal to AG.

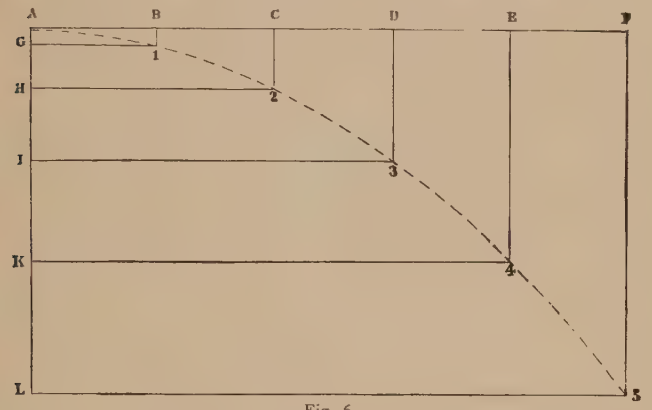


Fig. 6.

At the end of the next second the ball will have moved forward to C, and have been pulled down to 2, a distance equal to AH, etc. Hence, at the end of the first second, the ball will be at 1, at the end of the second second at 2, at the end of the third second at 3, at the end of the fourth second at 4, and at the end of the fifth second at 5. The ball would actually have moved on the curved path from A to 5. This curve is called a *parabola*.

QUESTIONS.

1. With what does the effect of a force in imparting motion increase? 2. What do we mean by the impulse of a force? 3. Give an example. 4. What is true of the impulse required to start and to stop a body? 5. Give an illustration. 6. With what does the impulse needed to put a body in motion increase?

7. What do we mean by the momentum of a body? 8. Give an example. 9. Give illustrations of momentum. 10. State the second law of motion. 11. Give an example. 12. What is true of the velocity which a force will impart to a body? 13. Give an example. 14. What is true of the effect of a force in producing motion, whether it act upon a body at rest or in motion? 15. Give an illustration. 16. What is true of the effect of a force in producing motion, whether it act alone or with other forces? 17. Give an illustration. 18. Describe the parallelogram of motion. 19. Falling bodies are illustrative of which law of motion? 20. Were it not for the resistance of the atmosphere, gravity would increase the velocity of a falling body how much each second? 21. How may we find the velocity of a body at the end of any given second? 22. Give an example. 23. How far does gravity cause a body to fall each second? 24. Give an illustration. 25. How much does gravity change the velocity of a rising body each second? 26. Give an example. 27. What effect has gravity upon the distance a body rises each second? 28. Give an example. 29. What effect has gravity upon a body fired horizontally? 30. Give an illustration.

CHAPTER VII.

THIRD LAW OF MOTION.

51. **Third Law of Motion.** — *Reaction is always equal and opposite to action; that is to say, the actions of two bodies upon each other are always equal, and in opposite directions.*

This law simply states the fact that a force always acts upon two portions of matter, and that the *stress* is equal upon both portions.

Illustrations. — A stone raised from the earth attracts the earth just as much as the earth attracts the stone. Gravity

pulls them equally, but in opposite directions. When the stone falls, the earth moves up to meet it. When the two meet, they have each the same momentum; but the earth, owing to its great mass, has only a very small velocity. When a cannon is fired, the powder pushes back upon the cannon just as hard as it pushes forward on the ball. Were the cannon as free to move as the ball, it would start back, or *recoil*, with the same momentum that the ball starts forward with, but of course with a less velocity.

We have an illustration of action and reaction in the collision of elastic bodies. Place two ivory balls of exactly the same size at the centre of the curved railway in Figure 7. Move one of the balls up to one end of the track, and let it roll back against the ball at rest. There will be a slight strain of compression when the balls strike, and this will develop a stress of elasticity between them, which will act equally upon both, and in opposite directions. This stress will stop the first ball, and start the second off with the velocity the first had on striking it.

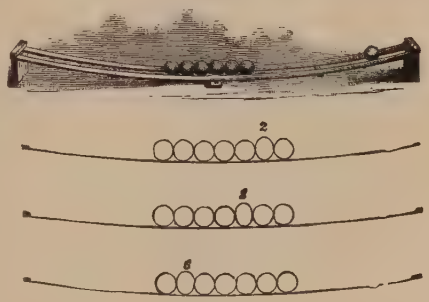


Fig. 7.

Place several ivory balls of the same size on the centre of the track, and allow the first ball to roll against the end of the line. All the balls will remain at rest except the last, which will be shot up the track. In this case the strain of compression and stress of elasticity have been sent along the line from ball to ball. Each ball has been compressed a little in turn, and in recovering itself has pushed upon the ball behind it enough to stop it, and upon the one in front enough to flatten it a little. Each ball except the last was kept from moving forward by the reaction of the ball in front.

52. **Reflected Motion.** — When an elastic body is thrown against a hard, smooth surface, reaction causes it to rebound. If it is thrown in a direction perpendicular to the surface, it will rebound in the same direction; if thrown obliquely, it will rebound obliquely in an opposite direction. The direction in which the body approaches the reflecting surface is its *line of incidence*, and that in which it rebounds the *line of reflection*. The angle included between the line of incidence and a perpendicular to the surface is called the *angle of incidence*. The angle included between the line of reflection and the perpendicular is called the *angle of reflection*.

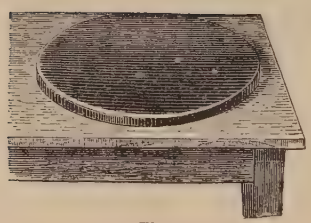


Fig. 8.

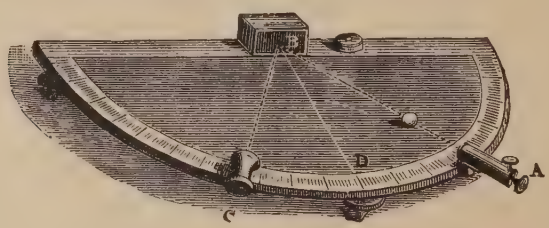


Fig. 9.

The angle of reflection is equal to the angle of incidence. This is the *law of reflected motion.*

Illustrations. — If an ivory ball is allowed to fall upon a marble slab, as shown in Figure 8, it will rebound perpendicularly nearly to the height from which it fell. If the ball were shot from *A*, Figure 9, it would, on striking the surface at *B*, rebound at *C*, making the angle of reflection, *CBD*, equal to the angle of incidence, *ABD*.

QUESTIONS.

1. State the third law of motion. 2. What fact does this law state? 3. Give the illustration of the falling stone. 4. Of the cannon and ball. 5. Of two elastic balls. 6. Of several elastic balls. 7. What takes place in reflected motion? 8. What is meant by the line of incidence? 9. By the line of reflection? 10. By the angle of incidence? 11. By the angle of reflection? 12. What is the law of reflected motion? 13. Give illustration.

CHAPTER VIII.

CENTRE OF GRAVITY AND EQUILIBRIUM.

53. **Centre of Gravity.** — There is for every body a point on which it will balance in every position in which it can be placed. This point is called the *centre of gravity* of the body. It received this name because the force of gravity, acting on the body on one side of this point, is always balanced by that acting on the other side.

The centre of gravity of a body always seeks to get into the *lowest possible position.* When a body at rest is suspended by a string, its centre of gravity will always be in a vertical line under the point of support. The force of gravity, which is really acting upon all the particles of which a body

is composed, has the same effect upon the body, as a whole, as if it were all applied to its centre of gravity.

54. **Position of the Centre of Gravity.** — When a body is uniform throughout, its centre of gravity is at its centre of figure.

Illustrations. — The centre of gravity of a circle or other regular figure cut out of a board is at the centre of the figure; and the centre of gravity of a sphere is at the centre of the sphere.

When the body is not uniform throughout, its centre of gravity will be away from its centre of figure, toward the denser or heavier side of the body.

Illustrations. — The centre of gravity of dice is at their centre of figure, and they are as liable to fall with one side down as another when thrown; but the centre of gravity of loaded dice is nearer their loaded side, so that they are very apt to fall with that side down.

The centre of gravity often lies entirely outside of the material of the body. When this is the case, the centre of gravity must be rigidly connected with the body in order to have the body balance on it.

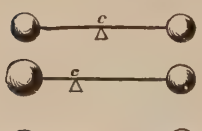


Fig. 10.

Illustrations. — The centre of gravity of a ring lies in the space enclosed by the ring, and the centre of gravity of a tin pail lies within the space enclosed by the tin.

A system of bodies may have a common centre of gravity lying outside of all of the bodies.

Illustrations. — The centre of gravity of two spheres (Figure 10) will lie somewhere on a line between their centres of gravity. If the spheres have the same mass, this point will be just midway between these centres. If one sphere has a greater mass than the other, the centre of gravity of the system will be nearer the centre of gravity of the larger sphere. If there is sufficient difference between their masses, their common centre of gravity may lie within the larger sphere.

Fig. 11.

55. **Kinds of Equilibrium.** — A body at rest is said to be *in equilibrium*. When a body, on being tipped a little, tends to return to its old position, it is said to be in *stable* equilibrium; when it tends to fall to a new position, in *unstable* equilibrium; and, when it rests equally well in every position, in *indifferent* equilibrium.

Fig. 12.

When a body is in stable equilibrium, its centre of gravity *rises* on tipping the body; when it is in unstable equilibrium, its centre of gravity *falls* on tipping the body; and, when it is in indifferent equilibrium, its centre of gravity *neither rises nor falls* on tipping the body.

Illustrations. — A rod balanced on the finger, as shown in Figure 11, is in *unstable* equilibrium, the centre of gravity being above the point of support. As soon as the rod begins to tip, its centre of gravity begins to fall. A cork balanced on the point of a needle, as shown in Figure 12, is in *stable* equilibrium, as the heavy forks bring the centre of gravity below the point of support. As soon as the cork begins to tip, its centre of gravity begins to rise. A sphere on a level surface is in *indifferent* equilibrium. The sphere rests on a single point; but, when the body is tipped, the centre of gravity always remains at the same distance above the point. A man on stilts, as shown in Figure 13, is in *stable* equilibrium in one direction, and in *unstable* equilibrium in another, the centre of gravity being above the points of support. The man is very liable to fall forward or backward, but not likely to fall to the right or left. As soon as he leans forward or backward, his centre of gravity begins to fall; but when he leans to the right or left, at first his centre of gravity rises. A table standing on three legs, as shown in Figure 14, is in *stable* equilibrium in every direction. The table cannot be tipped without raising its centre of gravity.

Fig. 13.

Fig. 14.

The lower the centre of gravity of a body, and the broader its base, the greater its stability. A

body will stand firmly, even though it leans, provided a vertical line from its centre of gravity falls within its base.

Illustrations. — A loaded wagon on an uneven road may tip considerably to one side without being overturned. If the load is piled up high, it is in greater danger of being overturned, as the vertical line from the centre of gravity is more likely to fall outside the base when the wagon tips. The famous Leaning Tower of Pisa, though it looks very unstable, is in stable equilibrium, as a vertical line from its centre of gravity falls within the base.

QUESTIONS.

1. What is meant by the centre of gravity? 2. Why was it so named? 3. What position does it always seek? 4. When a body at rest is hung by a string, where will its centre of gravity be? 5. What would be the effect of gravity upon a body as a whole, were it all applied to the centre of gravity? 6. When is the centre of gravity at the centre of figure? 7. Give illustrations. 8. When is the centre of gravity away from the centre of figure? 9. Give illustrations. 10. Is the centre of gravity always in the material of the body? 11. Give some cases where it is not. 12. What does any system of bodies have? 13. Give illustrations. 14. When is a body said to be in equilibrium? 15. Name the three kinds of equilibrium. 16. How can you tell in which equilibrium any body is? 17. What happens to the centre of gravity of a body on tipping it in each case of equilibrium? 18. Give the illustration of the rod balanced on the finger. 19. Of the cork balanced on a needle. 20. Of a sphere on a level surface. 21 Of a man on stilts. 22. Of a table on three legs. 23. Upon what does the stability of a body depend? 24. To what extent may a body lean, and yet stand firmly?

II.

ENERGY AND MACHINES.

CHAPTER IX.

WORK AND ENERGY.

56. **Position of Advantage.** — A body is said to be in a *position of advantage* with respect to a force, when it is so situated that it is possible for the force to move it.

Illustrations. — When a body is raised from the earth, it is in a position of advantage with respect to gravity, which may then put the body in motion by pulling it to the earth. We may say that the body may, by means of gravity, pull itself to the earth. A watch-spring, when wound up, is in a position of advantage with reference to elasticity, since it is possible for the spring to put itself in motion by unwinding itself by means of its elasticity.

57. **Work.** — Work is said to be done when any portion of matter is *moved against resistance.* Work may be done not only by men and animals, but also by forces.

Illustrations. — Work is done when a man raises a weight, or when a horse draws a load, or when the wind drives a vessel, or when gravity pulls down a clock-weight.

There are *two kinds* of work. One is that of *putting portions of matter into positions of advantage,* and the other is that of *quickening their speed.* The resistance overcome in the latter case is that of *inertia.*

Illustrations. — When a weight is raised from the earth, the work done by the force which raises the weight is that of putting it in a position of advantage. When the weight is allowed to fall freely to the earth again, the work done by gravity is that of increasing the speed of the body by overcoming its inertia.

58. **Measurement of Work.** — The work done in any case is equal to *the product of the force employed and the distance* through which it acts upon the body. A *foot-pound* of work is the work done by a force of one pound acting through a distance of one foot, or the work done in raising a pound one foot high. A *foot-poundal* of work is the work done by a poundal of force acting through one foot, or the work done in raising half an ounce one foot high.

Illustrations. — If I wish to raise five pounds twelve feet high, I must exert a force of five pounds; and that force must act upon the body for a distance of twelve feet: the work done is five times twelve, or sixty foot-pounds. The work done by eight poundals of force acting upon a body through a distance of twelve feet is equal to eight times twelve, or ninety-six foot-poundals.

59. **Energy.** — By *energy* is meant *capacity for doing work.*

Illustrations. — A weight raised from the earth is able to pull itself to the earth, and therefore has the capacity for doing a certain amount of work. The work done by the falling weight may be either that of increasing its own velocity, when

it falls freely, or of putting other bodies in motion, as when it is attached to the wheels of a clock.

A spring when wound up has a capacity for doing a certain amount of work. In unwinding, it may increase its own velocity, or it may put in motion the wheels of a watch.

Running water has a capacity for work. It may, for instance, turn the wheels of a mill.

60. **Two Kinds of Energy.** — Every portion of matter in a position of advantage possesses energy, or capacity for doing work; and the same is true of every portion of matter in motion.

The energy of a body due to its position of advantage is called *energy of position*, or *potential energy*. The energy of a body due to its motion is called *energy of motion*, or *kinetic energy*.

Illustrations. — The energy of a raised clock-weight, or of a coiled spring, is *potential;* while that of running water, or of a ball fired from a cannon, is *kinetic.*

The energy of visible masses of matter, whether potential or kinetic, is called *molar*, or *mechanical* energy; while the energy of the molecules and atoms of a body, whether potential or kinetic, is called *molecular* energy.

61. **Expenditure of Energy.** — Energy is always expended when work is done.

Illustrations. — When I raise a weight, I expend upon it a certain amount of the energy of my arm. When the weight falls to the earth again, it is drawn to the earth by the expenditure of its energy of position. When work is done by a moving body, it is always at the expense of some of its energy of motion. The speed of the body is lessened.

The energy expended by a force in doing work is always equal to *the product of the intensity of*

the force and the distance through which it acts. Energy is measured in *foot-pounds* and in *foot-poundals;* a foot-pound of energy being the energy used in doing a foot-pound of work, and a foot-poundal of energy that used in doing a foot-poundal of work.

Illustrations. — The energy expended by gravity in pulling five pounds down eight feet is equal to eight times five foot-pounds, or forty foot-pounds. The energy expended in raising a weight of fifteen pounds twenty feet is equal to twenty times fifteen foot-pounds, or three hundred foot-pounds.

The energy of a body in a position of advantage or in motion is always exactly equal to the energy expended in putting a body in its position of advantage, or in giving the body its motion.

Illustrations. — It takes eighty foot-pounds of energy to raise ten pounds eight feet from the earth; and ten pounds raised eight feet from the earth possesses just eighty foot-pounds of *potential* energy. It requires six hundred foot-poundals of energy to give a ball weighing three pounds a velocity of twenty feet a second; and a ball weighing three pounds, and having a velocity of twenty feet a second, has just six hundred foot-poundals of *kinetic* energy.

It takes just as much energy to stop a body as it does to put it in motion.

62. **Transformation of Energy.** — When a body is thrown upwards, its energy is at first entirely *kinetic.* As it rises, it moves slower and slower, and therefore loses kinetic energy; but, as it rises higher and higher from the earth, it gains *potential* energy. At its highest point the energy is entirely *potential.* When it falls, there is a gradual loss

of potential energy, since the body comes nearer and nearer to the earth. At the same time there is a gradual gain of *kinetic* energy, since the body moves faster and faster. When the body strikes the earth, the motion of the body as a whole is stopped; but its molecules and atoms are made to vibrate with greater rapidity. Its *molar* energy is now converted into *molecular* energy.

While the body was rising, *kinetic* energy was changed into *potential* energy; while it was falling, its *potential* energy was again changed back into *kinetic* energy; and when it struck the earth its *molar* energy was changed into *molecular* energy.

Whenever work is done, one kind of energy is changed into another, — either *kinetic* into *potential*, or *molar* into *molecular*, or the reverse.

63. **Energy is Indestructible.** — Whatever transformations energy may undergo, *the amount of energy always remains the same.* We can no more create or destroy energy than we can create or destroy matter.

QUESTIONS.

1. When is a body said to be in a position of advantage? 2. Give illustrations. 3. When is work said to be done? 4 Give illustrations. 5. What are the two kinds of work? 6. Give illustrations. 7. To what is the work done in any case equal? 8. What is a foot-pound of work? 9. A foot-poundal of work? 10. Give the illustration of the amount of work done. 11. What is meant by energy? 12. Give illustrations. 13. What are the two kinds of energy? 14. Give illustrations. 15. What is meant by molar energy? 16. By molecular energy? 17. What is always expended when work is done? 18. Give illustrations. 19. To what is the energy expended by

a force equal? 20. What is meant by a foot-pound of energy? 21. By a foot-poundal of energy? 22. To what is the energy of a body in a position of advantage or in motion equal? 23. Give illustrations. 24. How much energy does it take to stop a body? 25. Give all the transformations of energy which take place when a body is thrown upwards. 26. What takes place whenever work is done? 27. Can energy be destroyed?

CHAPTER X.

MACHINES.

64. **Definition of a Machine.** — A *machine* is an instrument by which *a force may be applied to do work.* The force applied to a machine is called the *power.* The *work* done by a machine is that of raising *weight*, or of overcoming some form of *resistance.*

Illustration. — A pair of scissors (Figure 1) is a good example of a simple machine. The *power*, which is here the strength of the fingers, is applied to the handles, so as to cause them to come together. The *work* done is that of cutting some material between the blades.

Fig. 15.

65. **Mechanical Powers.** — All machines, however complicated, are constructed out of four elements, called the *mechanical powers*, or the *simple machines.* These are the *lever*, the *wheel and axle*, the *pulley*, and the *inclined plane.*

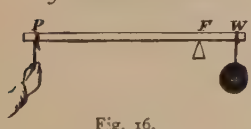


Fig. 16.

66. **The Lever.** — The *lever* is a rigid bar capable of turning upon a fixed point, or axis. The point on which the lever turns is called the *fulcrum;* and the distances from the fulcrum to the

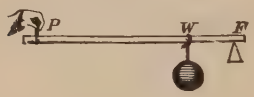


Fig. 17.

Fig. 18.

points where the power and weight are applied are called the *arms* of the lever.

When the fulcrum is between the weight and power, the lever is said to be of the *first order* (Figure 16); when the weight is between the ful-

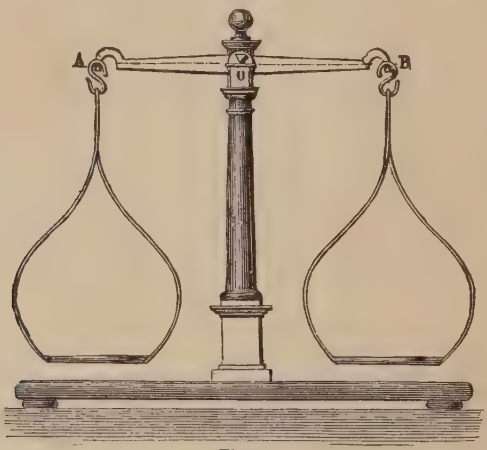


Fig. 19.

crum and power, the lever is said to be of the *second order* (Figure 17); and, when the power is between the weight and the fulcrum, the lever is said to be of the *third order* (Figure 18).

Illustrations. — An iron bar used for raising weights is a lever. A pair of scissors (Figure 15), a balance (Figure 19), and a pair of steelyards (Figure 20), are levers of the first order. A bar placed under a weight, so as to raise it (Figure 21), and a pair of nut-crackers (Figure 22), are examples of levers of the second order. The foot-crank (Figure 23) and the sugar-tongs (Figure 24) are levers of the third order.

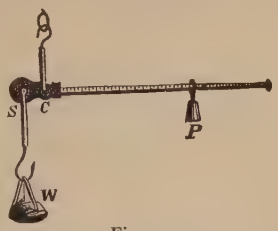


Fig. 20.

Fig. 21.

Fig. 22.

67. **The Wheel and Axle.** — The *wheel and axle* consists of a wheel or drum, *a* (Figure 25), mounted on an axle, *b*. The power and weight are applied to ropes, which pass, one over the wheel and the other over the axle, in opposite directions; so that one unwinds as the other winds up.

Fig. 23.

Illustrations. — The wheel and axle is often used for drawing water; the bucket, or *weight*, being applied to the *axle*,

and the counter-weight, or *power*, to the *wheel*. Elevators are usually raised by means of a wheel and axle. In almost

Fig. 24.

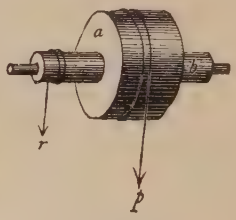


Fig. 25.

every kind of mill-work, wheels and axles are combined so as to act upon each other by *bands* or *belts* (Figures 26 and

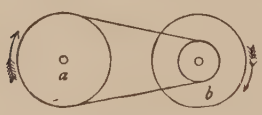


Fig. 26.

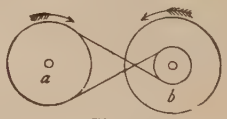


Fig. 27.

27), or by *cogs* (Figures 28 and 29). The *windlass* (Figure 30) and the *capstan* (Figures 31 and 32) are modifications of the wheel and axle.

68. **The Pulley.** — The *pulley* is a small grooved wheel turning freely in a frame called a *block*. It is a machine in which power is applied to do work by means of a *cord*, instead of a bar, as in the case of the lever. The wheel of the pulley serves simply to diminish friction at the points over which the cord is drawn. When the block is stationary,

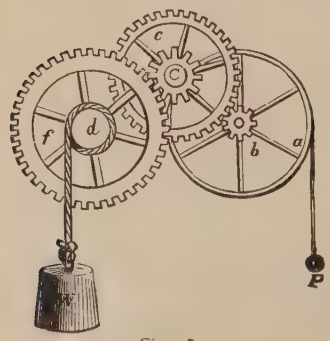


Fig. 28.

as in the case of the upper block, *C*, in Figure 33, the pulley is called a *fixed* pulley; and when the block is movable, as in the case of the lower pulley, *A*, in the same figure, the pulley is called a *movable* pulley.

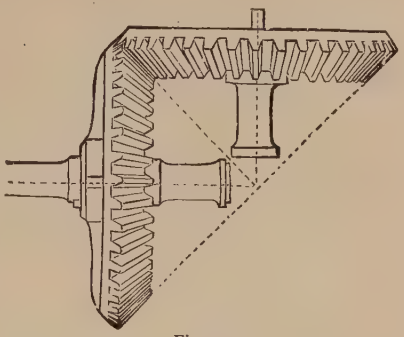


Fig. 29.

69. **Inclined Plane.** — An *inclined plane* is simply an inclined surface (Figure 34).

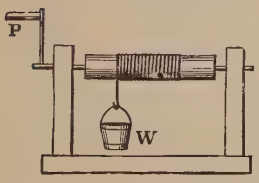


Fig. 30.

Illustrations. — The *skids*, or the plank used for loading logs or barrels on wagons, and the plank by which a steamer is loaded or unloaded, and by which barrels are rolled upon a platform (Figure 35), are all inclined planes.

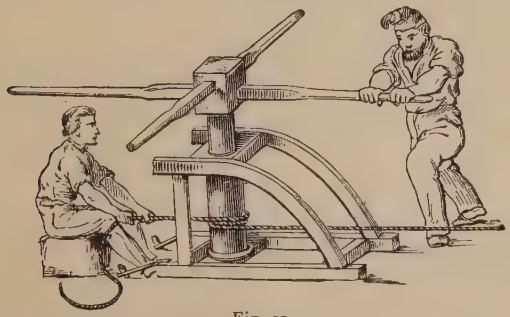


Fig. 31.

The *wedge* (Figure 36) is an inclined plane which is driven

under the weight to be raised, or between the parts to be

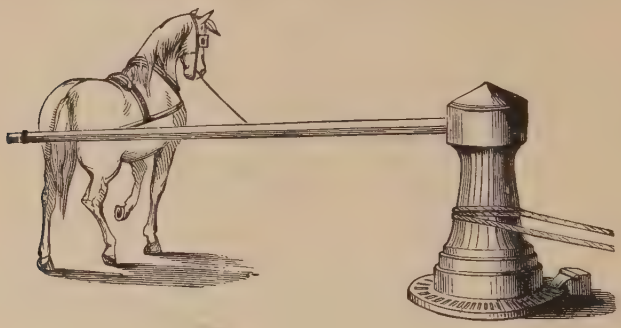


Fig. 32.

separated. The *screw* is an inclined plane in which the inclined surface winds around a cylinder in the form of a *thread*. The screw turns in a block, *N* (Figure 37), called the *nut*. Sometimes the screw is fixed and the nut movable, and sometimes the nut is fixed and the screw movable.

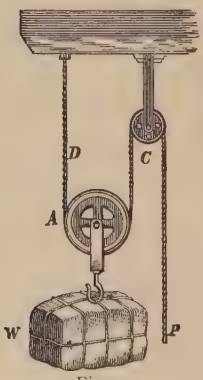


Fig. 33.

70. **Reasons for Using Machines.** — One of the objects to be attained by a machine is to *transmit the power from one point to another*, or to *change the point at which the power acts.* This is done by means of cords, belts, and rods.

A second end to be accomplished by the use of a machine is that of *changing the direction in which the power acts.*

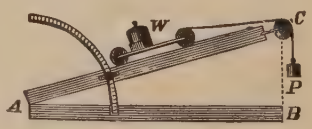


Fig. 34.

Illustration. — By means of two fixed pulleys, as shown

in Figure 38, the power of a horse is made to act upon the weight by means of the rope, and the *horizontal* pull of the horse is changed into an *upward* pull upon the weight.

Fig. 35.

A third end to be attained by a machine is to *make the power act through a different distance from that through which the weight is raised*, or to *change the velocity with which the power acts* upon the weight, or the resistance to be overcome. The velocity with which the power acts may be changed by the use of pulleys and wheels.

Fig. 36.

Illustrations. — By the use of two pulleys, one in the movable and one in the fixed block (Figure 39), the power which is at the end of the cord will have to move two feet in order to raise the weight one. By the use of six pulleys, three in the movable and three in the fixed block, as shown in Figure 40, the power can be made to move six feet in order to raise the weight one.

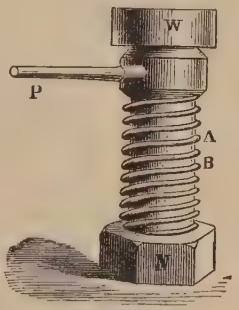


Fig. 37.

By the use of a windlass and a fixed pulley in a frame, as shown in Figure 41, the power applied to the spokes or to a crank may be made to raise a weight vertically. In this case, both the direction and the velocity of the power are

changed. The power will have to move over the circumference described by the end of the crank in order to raise the weight the circumference of the drum.

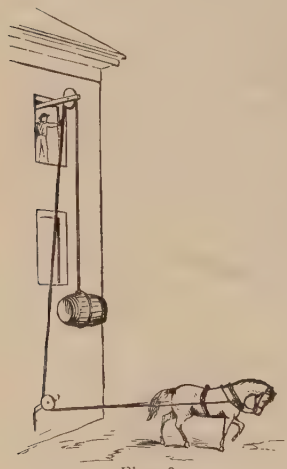


Fig. 38.

In the *crab* (Figure 42), the power applied to the cranks *C C* turns a small cog-wheel *P*, called the *pinion*, which acts upon the toothed wheel *W*, so as to turn the barrel *D*, to which the weight is attached. In this case the power must act through the circumference described by the end of the crank in order to turn the pinion around once; and the pinion must turn several times in order to turn the barrel once. The crab may be used in the frame of Figure 41, instead of a single windlass.

In the *derrick* (Figure 43) the crab is used at the bottom of the *mast*, in connection with a system of pulleys suspended from the end of the *boom*. In this case, the rate at which the power acts upon the weight is diminished still more than in the last.

In the *crane*, shown in Figure 44, the crab is replaced by a more powerful piece of mechanism, shown in Figure 45. The barrel *A*, to which the rope or chain is attached, is turned by the cog-wheel *B*: this wheel is turned by the pinion *C*. This pinion is on the same axle as the pinion *E*, which is turned by the cog-wheels *D* and *F*. These cog-wheels are turned by the pinions *L* and *K*; which, finally, are turned by the power applied to the cranks *L* and *K*.

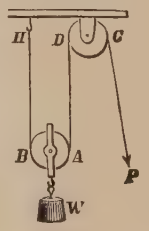


Fig. 39.

Whenever, in wheel-work, a small wheel is made to act upon a large one, the rate at which the power acts upon the resistance is *diminished*; and,

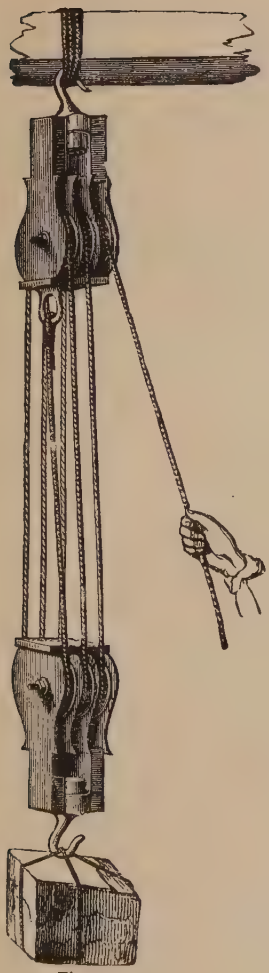


Fig. 40.

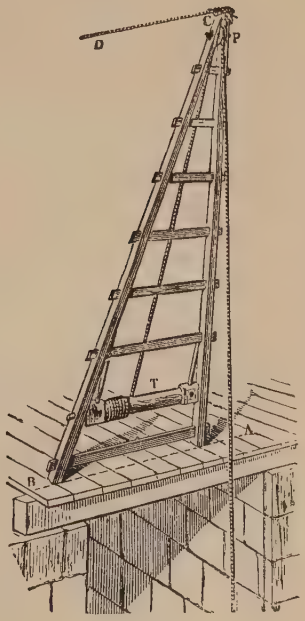


Fig. 41.

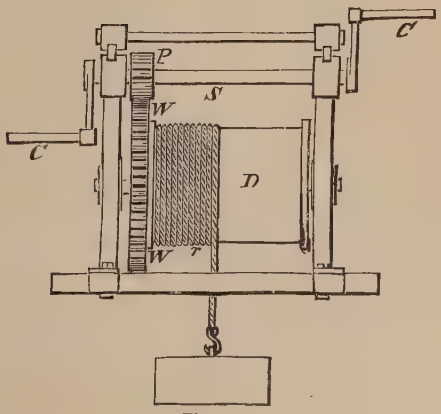


Fig. 42.

whenever a large wheel acts upon a small one, the rate at which the power acts upon the weight is *increased.*

71. **The Amount of Work done by a Machine.** — The *work* done by a machine is always exactly equal to *the energy expended by the power* upon the machine. A machine is not an instrument for creating power, but simply for transforming the energy of the power into work. The work done by a machine is partly the *useful* work of raising a weight or of overcoming a resistance, and partly the *useless* work of overcoming the friction and other resistance to motion in the machine itself. The useful work done by a machine is never quite equal to the energy expended upon the machine. The useless work is lessened by keeping the parts of the machine well oiled, so as to diminish friction as much as possible.

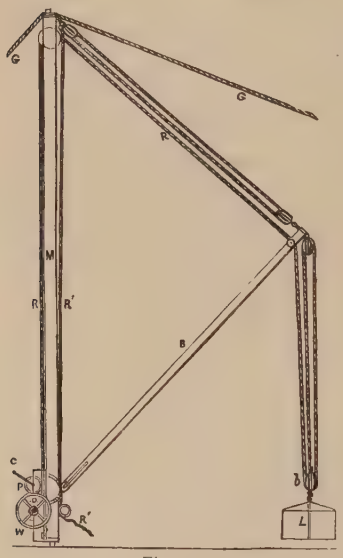


Fig. 43.

72. **The Great Law of Machines.** — The energy expended upon a machine is equal to the power multiplied by the distance through which it moves. The work done by a machine is equal to the weight

multiplied by the distance which it is raised. Hence *the power multiplied by the distance through which it acts is equal to the weight multiplied by the distance it is raised.* This is the great fundamental law of machines; but it is strictly applicable only to an *ideal* machine; that is, to one which would itself offer no resistance to motion.

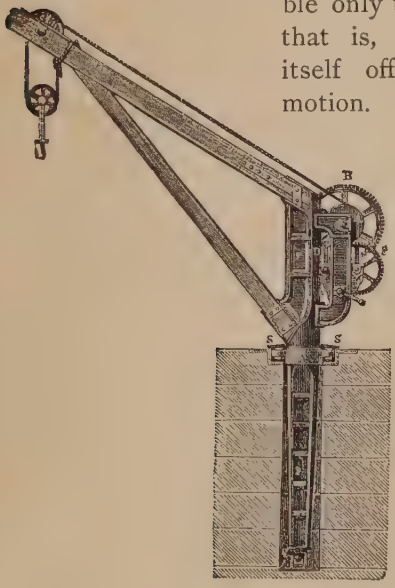


Fig. 44.

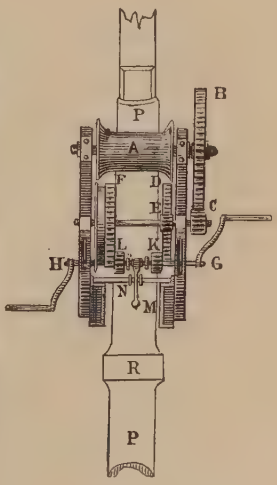


Fig. 45.

73. **Gain and Loss of Power.** — When the power moves faster than the weight, there is said to be a *gain* of power; since the power then moves a weight greater than itself. The faster the power moves, compared with the weight, the greater the gain of power, or the larger the weight that will be raised by the power. When the power moves

slower than the weight, there is said to be a *loss* of power; since the power then moves a weight smaller than itself.

Whenever there is a *gain in power*, there is *an equal loss in speed;* and, whenever there is a *loss of power*, there is an *equal gain in speed.*

QUESTIONS.

1. What is a machine? 2. What do we mean by the power? 3. What is the work done by a machine? 4. Of what elements are all machines composed? 5. What are these elements called? 6. What is a lever? 7. Name and describe the different orders of levers. 8. Give illustrations of levers. 9. What is the wheel and axle? 10. How are the weight and power applied? 11. Give illustrations. 12. How are wheels and axles combined in mill-work? 13. What are the two modifications of the wheel and axle? 14. What is an inclined plane? 15. Give illustrations. 16. What are the two modifications of the inclined plane? 17. What is one of the ends to be attained by the use of a machine? 18. By what means is this end attained? 19. What is a second end to be attained? 20. Give an illustration. 21. What is a third end? 22. By what means is this end attained? 23. Give the illustration of the pulleys. 24. Of the windlass and pulleys. 25. Of the crab. 26. Of the derrick. 27. Of the crane. 28. When, in wheel-work, is the rate at which the power acts upon the weight increased, and when diminished? 29. To what is the work done by a machine always equal? 30. What are the two kinds of work done by a machine? 31. What is true of the amount of the useful work? 32. How may the useless work be lessened? 33. What is the great law of machines? 34. To what kind of a machine alone is this law strictly applicable? 35. When is there said to be a gain of power in a machine? 36. Why? 37. When is there said to be a loss of power? 38. Why? 39. What is needed to make a small power raise a very large weight? 40. What is true of the gain or loss of speed in any case?

III.

STATES OF MATTER.

CHAPTER XI.

FLUIDS.

74. **The Three States.** — Matter exists in three different *states*, known as the *solid*, the *liquid*, and the *gaseous*.

Illustrations. — Ice is a solid, water is a liquid, and steam and air are gases.

75. **Difference between the Three States.** — The chief difference between the three states of matter is in the strength of *cohesion*, or attraction, among the molecules. This is comparatively *strong* in *solids*, very *weak* in *liquids*, and entirely *wanting* in *gases*.

In *solids* the molecules have certain fixed limits within which they move with freedom, but from which they are unable to escape. In *liquids* the molecules move about throughout the entire mass with the utmost freedom; but they never escape from the influence of cohesion. In *gases* the molecules are not under the slightest restraint from

cohesion : hence they move in straight lines. They are continually striking together, and rebounding again ; but after each rebound they move on in straight lines till they encounter other molecules.

If a piece of a solid is placed in an empty vessel, it will either retain its own shape completely, as in the case of a stone, or else conform to the shape of the vessel slowly and imperfectly, as in the case of pitch or wax. If a small amount of a liquid is put into an empty vessel, it will conform to the shape of the vessel at once and perfectly ; but it will not fill the vessel. It will sink into the lowest part, and be separated by a definite surface from the space above. If any portion of a gas, however small, is placed in an empty vessel, however large, it will completely fill the vessel.

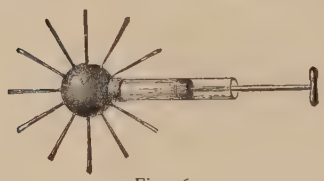


Fig. 46.

76. **Fluids.** — On account of the freedom of their molecular motion, and the readiness with which their parts *flow* over or among each other, gases and liquids are frequently classed together as *fluids*. They have several characteristics in common.

77. **Pascal's Law.** — One of the most remarkable characteristics of a fluid is the way in which it transmits pressure. *If any pressure is brought to bear on any portion of the surface of a fluid which fills a closed vessel, a pressure just equal to it will be transmitted through the fluid to every equal portion of surface.* This law was first stated by Pascal, and is therefore known by his name.

Illustrations. — A tube (Figure 46) provided with a piston is fitted into a hollow globe which is pierced with a number of holes in a circle around it. Fill the globe and tube with water, and push in the piston. The water spouts out of all the holes with equal force.

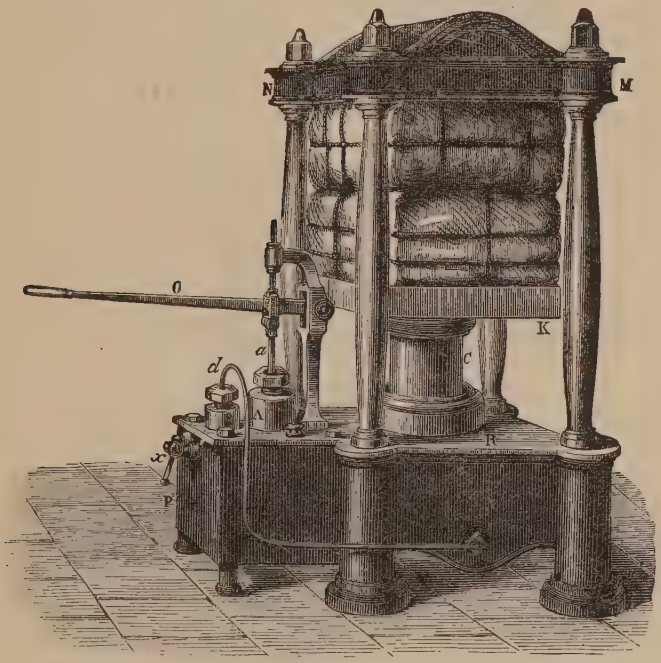


Fig. 47.

The *hydraulic press*, one form of which is shown in Figures 47 and 48, is an illustration of Pascal's law. It consists of two cylinders, *A* and *B*, one large and the other small, connected by the pipe *d*. The piston *a* in the cylinder *A* is worked by the handle *O*, and forces water into the large cylinder *B*, where it presses up the piston *C*. If the end of the piston *C* is a thousand times as large as that of the

piston *a*, a pressure of two pounds on *a* would exert a pressure of two thousand pounds, or one ton, upon *C*. If a man, in working the handle *O*, forces down the piston *a* with a pressure of fifty pounds, he would bring to bear upon *C* a pressure of twenty-five tons.

This press, which is one of the most powerful machines ever constructed, is used for pressing cotton, hay, cloth, etc., into bales; for extracting oil from seeds; for testing cannon, boilers, etc.; and for raising ships out of the water.

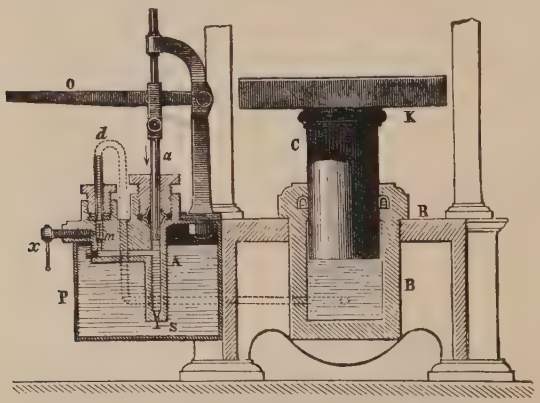


Fig. 48.

78. **The Principle of Archimedes.** — *A body in a fluid is buoyed up by a force equal to the weight of the fluid it displaces.* This fact was discovered by the ancient philosopher Archimedes.

Illustration. — Take a cup and a cylinder which just fills it, hang them to one pan of a balance (Figure 49), and counterpoise them in the air by adding weights to the other pan. Hang the cylinder in a vessel of water, as shown in the figure. The water lifts the cylinder up. Fill the cup with water, and the beam will again become horizontal. The cup holds just as much water as the cylinder displaces.

79. **To Find the Weight of a Body's Bulk of a Liquid.** — To find the weight of a body's bulk of a liquid, first hang the body to one pan of a balance, and counterpoise it by weights in the other pan. Then hang it in water, and add weights to its side till the beam is again horizontal. The

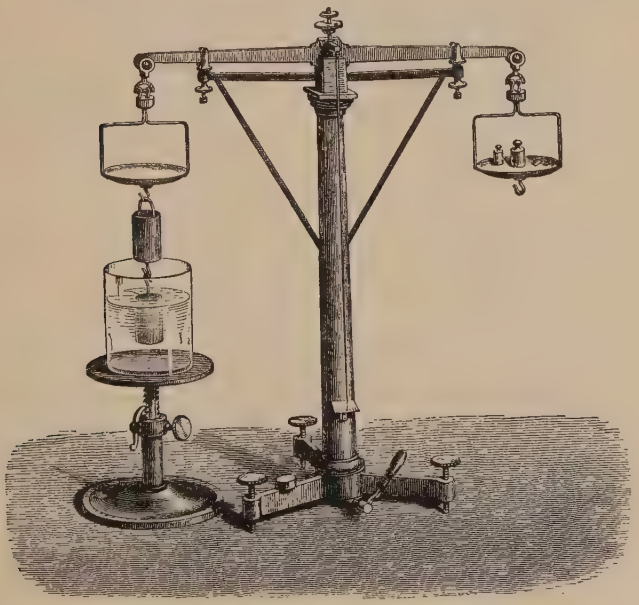


Fig. 49.

weights added will be equal to the weight of the body's bulk of water.

Illustrations. — Hang a piece of copper to one pan of a balance, and counterpoise it by weights in the other pan. Then hang it in water, as shown in Figure 50, and add weights to its pan till it sinks into the water enough to make the beam again horizontal. Suppose it takes fourteen grains to

do this: the weight of water equal in bulk to the copper is then fourteen grains. Suppose the piece of copper weighs a hundred and twenty-three grains: the copper is then about eight times and eight-tenths as heavy as water.

Counterpoise a glass globe containing mercury in air, in the same way as before, and then hang the globe in water, as shown in Figure 51, and add weights to the pan to which

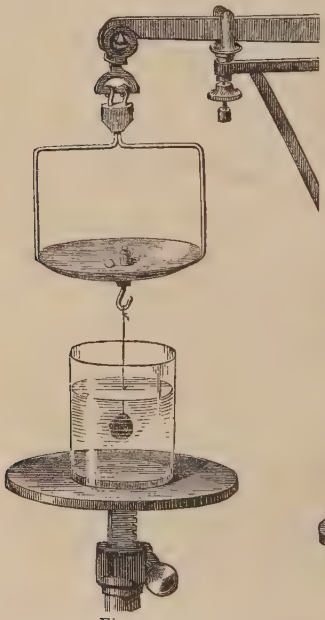


Fig. 50.

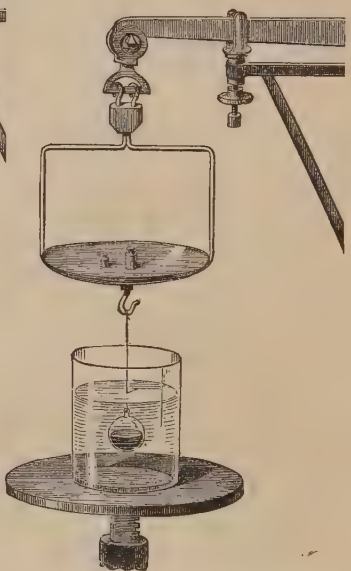


Fig. 51.

the globe is hung, till equilibrium is restored. Suppose it takes forty-four grains to do this: the weight of the globe's bulk of water is then forty-four grains. Again: counterpoise the ball in air, and then hang it in alcohol, and add weight to its pan till equilibrium is restored. It will take thirty-five grains to do this. The weight of the globe's bulk of alcohol is therefore thirty-five grains. Alcohol is thus seen to be about eight-tenths as heavy as water.

The weight of a substance, compared with the weight of its bulk of pure water at a temperature of sixty degrees, is called its specific gravity.

80. **Forces Acting upon a Body immersed in a Fluid.** — A body when immersed in a fluid is acted upon by two forces, — one equal to its own weight, which tends to make the body sink; and one equal to the weight of the fluid displaced, which tends to make the body rise. When a body displaces *more than its own weight* of a fluid, it

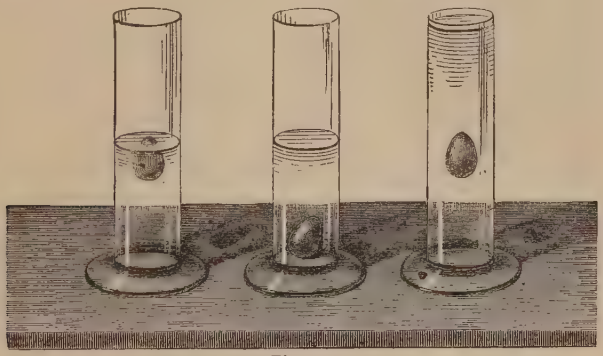


Fig. 52.

will *rise* in that fluid; when it displaces *less than its own weight*, it will *sink;* and, when it displaces *just its own weight*, it will *remain suspended* wherever it happens to be.

Illustrations. — An egg placed in salt water (Figure 52) rises to the surface, because it displaces more than its own weight of the brine. When it is put into fresh water, it sinks to the bottom, because it displaces less than its own weight of the water. When it is put into a proper mixture of fresh water and brine, it will remain suspended in the fluid, because it displaces just its own weight of the mixture.

81. **Floating Bodies.** — Every body *floating* in a fluid *displaces its own weight of the fluid.*

Illustrations. — A ship displaces its own weight of water. The heavier the ship is loaded, the deeper she sinks into the water. A solid piece of iron sinks in water; but when the iron is shaped into a hollow vessel, as in the case of iron ships, the vessel will float on the water, since it will then displace its own weight of water before it sinks to the surface.

Fig. 53.

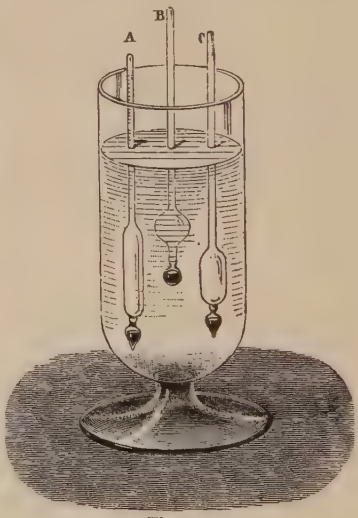


Fig. 54.

A balloon (Figure 53) displaces its own weight of air. By throwing out the sand which is used as ballast, the balloon is made lighter, so as to displace more than its own weight of air. It then rises till it comes into more highly rarefied air, where it displaces just its own weight, when it again floats along at the same level. If some

of the gas is allowed to escape, the balloon becomes less in bulk, and so displaces less than its own weight of air. It then sinks until it again displaces its own weight.

Hydrometers usually consist of a glass tube with a bulb blown upon it, and weighted at the bottom. Common forms of this instrument are shown in Figure 54. When put in a liquid, they sink in it till they displace their own weight. The deeper they sink in a liquid, the less its specific gravity. Their stems are graduated in such a way, that the number on the stem at the surface of the liquid indicates the specific gravity of the liquid.

QUESTIONS.

1. Name the three states of matter. 2. Give an illustration of each. 3. What is true of the strength of cohesion in each? 4. What is true of the molecular motion of each? 5. What is the result when a small portion of each is placed in an empty vessel? 6. What two states of matter are often classed together as fluids? 7. Why? 8. What is one of the most remarkable characteristics of a fluid? 9. State Pascal's law. 10. Give the illustration of the hollow globe. 11. Describe the hydraulic press. 12. Describe its action. 13. What are some of its uses? 14. State Archimedes's principle. 15. How came it to be designated by his name? 16. Give the illustration of the cylinder and cup. 17. How can we find the weight of a body's bulk of a fluid? 18. Give the illustration of the piece of copper. 19. Of the glass globe. 20. What do we mean by the specific gravity of a substance? 21. To what two forces is a body immersed in a fluid subjected? 22. When will such a body sink? 23. When will it rise? 24. When will it remain suspended in the fluid? 25. Give the illustration of the egg. 26. How much of a fluid is displaced by a floating body? 27. Give the illustration of a ship. 28. Of an iron ship. 29. Of a balloon. 30. Of a hydrometer.

CHAPTER XII.

PROPERTIES OF GASES, LIQUIDS, AND SOLIDS.

82. **Expansibility of Gases.** — The most remarkable property of a gas is its capacity for *indefinite expansion.* This is due to the absence of cohesion and to the rapidity with which its molecules are moving in straight lines.

Illustration. — Put a rubber bag, partially filled with air, under the receiver of an air-pump, and exhaust the air from the receiver. As the air becomes exhausted, the bag fills out, as shown in Figure 55.

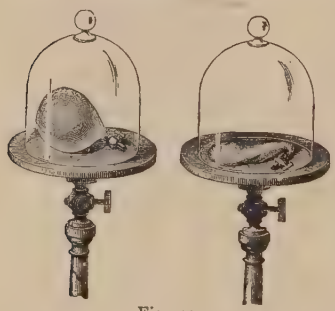


Fig. 55.

Explanation. — It is estimated that the molecules of air are moving at the rate of over sixteen hundred feet a second. In a cubic yard of air there are two pounds of these molecules. The expansive force of a cubic yard of air is therefore equal to the force of a two-pound cannon-ball moving at the rate of sixteen hundred feet a second, or of a mile in three seconds and a half. Could all the motions of the molecules of the air be turned into one and the same direction, the result would be a hurricane sweeping over the earth, whose destructive violence not even the Pyramids could withstand. "Living, as we do, in the midst of a molecular tornado capable of such effects, our safety lies wholly in the circumstance that the storm beats equally in all directions at the same time; and the force is thus so exactly balanced, that we are wholly unconscious of the tumult."

83. **Diffusion of Gases.** — When any two gases

are brought into contact, they rapidly mix with each other. This *mixture of gases, when brought into contact,* is called *diffusion.* It is due to the fact that the molecules are far apart and in constant motion. The molecules of the one gas quickly move into the spaces among the molecules of the other gas.

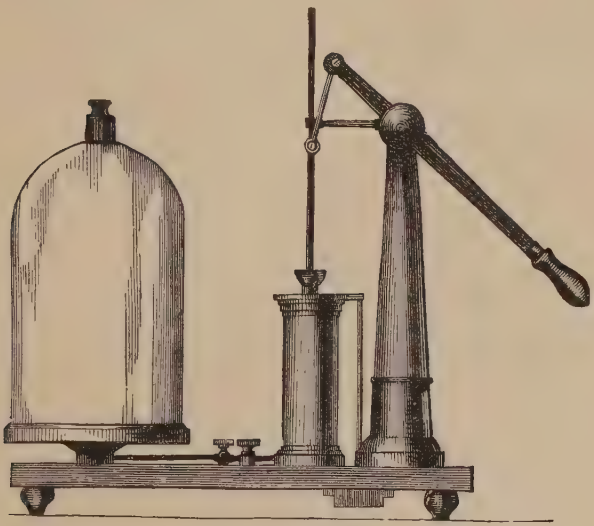


Fig. 56.

84. **The Air-Pump.** — A common form of *air-pump* is shown in Figure 56, and the internal structure of a similar one in Figure 57. It consists of a flat *plate* for holding the *receiver E.* The plate is connected by a tube with a *cylinder,* in which a piston is moved up and down by means of the handle. There is a valve *S* in the piston, which opens upwards, and which is pressed down

by a little spiral spring above it. There is a second valve S' at the bottom of the cylinder, which is fastened to the end of a rod passing through the piston. When the piston is drawn up, this valve is opened by the friction of the rod in the piston; and, when the piston is pushed down, this valve is closed by the same means. The pump-plate and the mouth of the receiver are both ground flat, so as to form an air-tight joint. As the piston

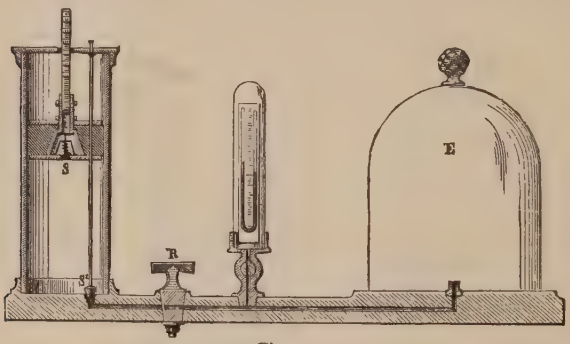


Fig. 57.

is drawn up, the air in the receiver expands, and a portion of it passes out through the open valve S' into the cylinder behind the piston. When the piston is again pushed down, the valve S' is closed; the valve S is opened by the pressure of the air below it, and this air passes through it into the space above the piston. As the piston is again raised, more air passes from the receiver into the cylinder; and so on, till the air is nearly all exhausted from the receiver.

85. **Liquids are nearly Incompressible.** — Gases are readily compressed, but liquids are nearly incom-

pressible. This is one of the most essential points of difference between a liquid and a gas. It was thought for a long time that liquids were entirely incompressible.

Illustration. — In the year 1661 some Florentine philosophers, wishing to ascertain whether water was compressible, filled a thin globe of gold with this liquid, closed it perfectly tight, and then subjected it to an enormous pressure in order to flatten the globe so as to diminish its capacity. They failed to compress the water, but discovered the porosity of gold (19); for the water forced its way through the pores of the gold, and stood on the outside like dew.

86. **Liquids tend to Assume a Globular Form.** — When left to itself, a liquid always assumes a globular form.

Illustrations. — Prepare a mixture of water and alcohol which shall be just as heavy as sweet oil, bulk for bulk, and introduce some of the oil carefully into the centre of this mixture by means of a dropping-tube: the oil will neither rise nor sink, but gather into a beautiful sphere.

Rain-drops, dew-drops, and the manufacture of shot, illustrate this tendency of the molecules of liquids. In the manufacture of shot, melted lead is poured through a sieve at the top of a very high tower; and the drops, in falling, take the form of spheres, which become solid before they reach the bottom.

87. **The Pressure of a Liquid is Proportional to the Depth.** — The pressure of a liquid at any point is *proportional to the depth* of the liquid above that point, and entirely *independent of the quantity* of the liquid above it.

Illustration. — In Figure 58 is shown a strong cask having a small tube thirty or forty feet high fastened into its top.

If water is poured into the tube so as to fill the cask and tube, the pressure at the bottom of the cask will be sufficient to burst the cask. The pressure on the bottom of the cask is the same that it would be, were the cask itself thirty or forty feet high, and filled with water.

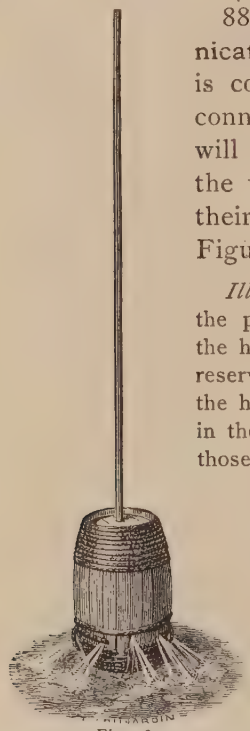


Fig. 58.

88. **Rise of Liquids in Communicating Vessels.** — When a liquid is contained in a series of vessels connected with each other, the liquid will rise to the same height in all the vessels, no matter what may be their size or shape, as shown in Figure 59.

Illustrations. — Water will rise in all the pipes connected with a reservoir to the height of the level of the water in the reservoir. If the upper stories of any of the houses are above the level of the water in the reservoir, the water will not rise to those stories.

Artesian wells and deep-seated *springs* are illustrations of this same fact. These are openings into internal reservoirs of water which are somewhere in communication with water at a higher level than the spring, or the mouth of the well. Springs are natural openings into such reservoirs, and Artesian wells are artificial openings. An Artesian well is shown in Figure 60. *AB* and *CD* are two layers which water cannot penetrate. The space between these is supposed to be filled with water above the level of the surface at *H*: hence the water rises through the well, and overflows at the mouth. Artesian wells are often bored several thousand feet deep.

89. **Solids tend to assume a Crystalline Structure.** — Whenever a solid is formed under circum-

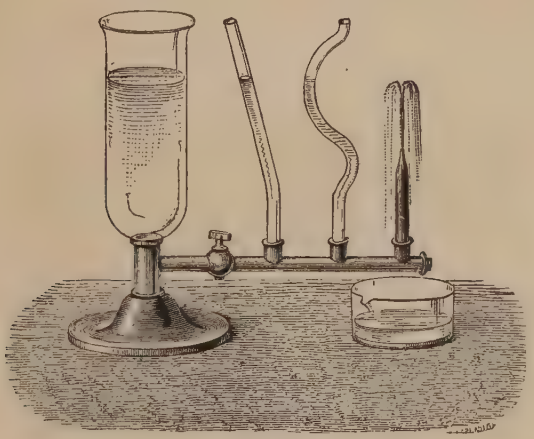


Fig. 59.

stances which leave the molecules free to arrange themselves as they will, it assumes a *crystalline*

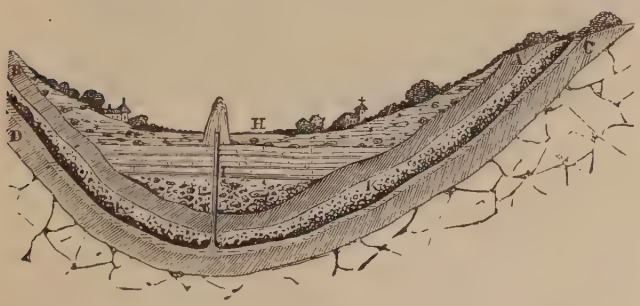


Fig. 60.

structure, or one made up of *crystals*. These are regular geometrical forms, which are different for different substances.

Illustrations — Snowflakes, when examined with the microscope, are seen to be composed of beautiful crystals, as shown in Figure 61. The same is true of the delicate frost on the window-pane.

90. **Properties of Solids.** — A body is said to be *tenacious* when it is *difficult to pull it in two.* All

Fig. 61.

solids are more or less tenacious, but they differ much in the degree of their tenacity. A body is said to be *hard* when it is *difficult to scratch or indent it;* that is to say, when it is *difficult to displace its molecules.* All solids are *elastic* within certain limits; and this elasticity may be developed by stretching, bending, twisting, compression, or any kind of strain whatever. Different solids, however, differ greatly in the degree, or *limit,* of

their elasticity. When the strain is carried beyond this limit, the body must either break, or take a new form. A body which is *apt to break when strained beyond the limit of elasticity* is said to be *brittle.* A brittle substance is not always *easily* broken. It is often difficult to strain it beyond the limit of its elasticity. It is not easy to break a glass rod an inch in diameter; yet glass is the most brittle substance known. Substances which can *readily take and retain new forms* are said to be *malleable* or *ductile.* A malleable substance is one that can be *hammered or rolled into sheets,* and a ductile substance one that can be *drawn into wire.* All malleable substances are to some extent ductile; but the most malleable are not the most ductile.

Fig. 62. Fig. 63.

Illustration. — *Gold* is one of the most malleable of the metals. In the manufacture of *gold-leaf* it is hammered out into sheets so thin that it takes from three hundred thousand to three hundred and fifty thousand of them to make the thickness of a single inch.

91. **Capillarity.** — When a liquid wets a vessel which holds it, as in the case of water in a goblet, the water rises a little on the sides of the vessel, as shown in Figure 62. When the liquid cannot wet the vessel, as in the case of quicksilver in a glass goblet, the liquid is depressed a little around the sides of the vessel, as shown in Figure 63.

If a tube is plunged into a liquid which will wet

it, as in the case of a glass tube in water, the liquid will rise higher within the tube than it is on the outside, as shown in Figure 64. The finer the tube, the higher the liquid rises in it. If a tube is plunged into a liquid which will not wet it, as in the case of a glass tube in quicksilver, the liquid will fall lower within the tube than it is on the outside, as shown in Figure 65. The finer the tube, the lower the liquid is depressed.

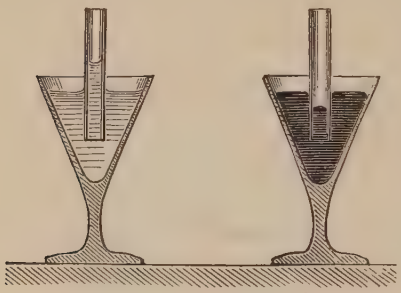


Fig. 64. Fig. 65.

This peculiar action of liquids in contact with the surface of solids is called *capillarity*, because it is especially manifest in *capillary*, or hair-like, tubes (from the Latin *capillus*, a hair).

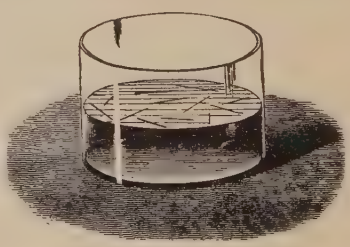


Fig. 66.

Illustrations. — A lamp-wick is full of tubes and pores; and capillary force draws the oil up through these to the top of the wick, where it is burned. When one end of a cloth is put into water, capillary force draws the water into the tubes and pores of the cloth, and the whole soon becomes wet. In the same way, any other porous substance soon becomes wet throughout, if a corner of it is put into water. Blotting-paper is full of pores, into which the capillary force

draws the ink. The use of a towel for wiping any thing which is wet depends on the same principle. Small steel needles will float on water when placed carefully on the surface (Figure 66). Some insects walk on water (Figure 67). In all these cases the bodies are not *wet* by the liquid, and consequently

Fig. 67.

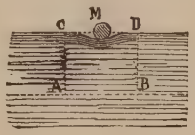


Fig. 68.

depressions are formed around them by capillary action, as shown in Figure 68. The liquid displaced by one of these bodies is really equal to that which would fill the whole depression, or the space below the dotted line *CD;* and this liquid would, in every case, be equal to the weight of the floating body.

QUESTIONS.

1. What is the most remarkable property of a gas? 2. To what is the expansiveness of a gas due? 3. Give the illustration of the rubber bag. 4. At what rate are the molecules of air moving? 5. To what is the expansive force of a cubic yard of air equal? 6. What would be the result were the motions of all the molecules turned in the same direction? 7. Why do we not feel this molecular tornado? 8. What is meant by the diffusion of gases? 9. What takes place in diffusion? 10. Describe the air-pump. 11. Explain its action. 12. What is one of the most essential points of difference between a liquid and a gas. 13. Give the Florentine experiment. 14. What form do liquids tend to assume? 15. Give illustrations of this tendency. 16. To what is the pressure of a liquid proportional? 17. Give the illustration of the cask. 18. What is true of the rise of liquids in communicating vessels? 19. Give the illustration of aqueducts. 20. Of springs and Artesian wells. 21. What structure do solids tend to assume? 22. Give illustrations. 23. When is a body said to

be tenacious? 24. What is true of solids as regards tenacity? 25. When is a body said to be hard? 26. What is true of solids as regards elasticity? 27. When is a body said to be brittle? 28. Is a brittle substance always easily broken? 29. When is a substance said to be malleable or ductile? 30. What is the difference between the two? 31. What is true of the malleability of gold? 32. When a liquid can wet the vessel which holds it, what takes place along the side of the vessel? 33. When it cannot wet it? 34. What takes place when a tube is put into a liquid which can wet it? 35. Which cannot wet it? 36. Does the size of the tube make any difference? 37. What name is given to this action of liquids? 38. Give illustrations of capillarity. 39. Explain how needles and other heavy bodies can be made to float on water.

CHAPTER XIII.

ATMOSPHERIC PRESSURE.

92. **Pressure of the Air.** — The pressure of the air may be illustrated by the following experiment: place a small bell-jar, open at both ends, on the plate of the air-pump, and cover the top of the jar with the palm of the hand. When the air is exhausted from the jar, the hand is pressed firmly down upon the mouth of the jar. This illustrates the *downward pressure* of the air. It was not perceived at first, because the downward pressure of the air upon the hand was balanced by the upward pressure of the air within the jar.

The pressure of the air at the level of the sea is about fifteen pounds to the square inch. As we ascend in the atmosphere, this pressure is less and less, because there is less depth of air above us.

93. **Rise of Liquids in Exhausted Tubes.** — A liquid will rise in any exhausted tube which opens into it. The height to which the liquid will rise varies with its density. Water will rise somewhat over thirty feet, and mercury about thirty inches. The rise of the liquid in such a tube is due to the pressure of the atmosphere on the surface of the liquid: this is about fifteen pounds to the square inch. When the air is removed from a vessel or tube which opens into a liquid, there would be no pressure within the tube to balance the pressure of the atmosphere on the outside, if the liquid did not rise in the tube: hence the liquid rises in the tube till its pressure is equal to fifteen pounds to the square inch, or to that of the atmosphere on the outside.

Fig. 69.

Illustrations.—A glass tube closed at one end, and somewhat over thirty inches in length, is filled with mercury, closed with the thumb, and inverted in a cup of mercury, as shown in Figure 69. The mercury will fall in the tube to within about thirty inches of the surface of the mercury in the cup.

This experiment was first tried by an Italian named Torricelli: hence such a tube is known as a *Torricellian tube*, and the empty space above the column of mercury as a *Torricellian vacuum*.

In drinking lemonade through a straw, the air is first drawn out of the straw by the mouth, and the liquid is forced up through the straw by the pressure of the air on the surface.

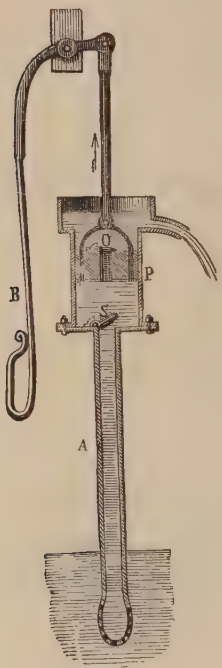


Fig. 70.

In drawing water with an ordinary pump, the air is first removed from the barrel and tube by the action of the piston; and the water is then forced up through the tube into the barrel by the pressure of the atmosphere on the surface of the water in the well or cistern. The two kinds of pumps in ordinary use are shown in Figures 70 and 71. Each has a valve at the top of the tube, which communicates with the well or cistern. The first has a valve in the piston, which moves up and down in the barrel. In the second the piston is solid; but there is a second valve in the discharge-pipe, which, in this case, opens from the bottom of the barrel. With the former, the water is *lifted* out of the barrel every time the piston is raised; while with the latter the water is *forced* out of the barrel every time the piston is pushed down. The former is called the *lifting-pump*, or *suction-pump;* and the latter, the *force-pump*. With the former, water can be raised only about thirty feet high; while with the latter it can be raised to any desired height.

In either pump, as the piston is raised, the water is forced up through the tube and the valve *S*, into the barrel; and, as the piston is pushed down, this valve closes, and keeps the

water in the barrel from passing back into the well. The valve *O* at the same time opens, and allows the water in the barrel to pass above the piston in the lifting-pump, and into the discharge-pipe of the force-pump. When the piston rises again, the valve *O* closes.

94. **The Siphon.** — The *siphon* is used for transferring liquids from one vessel to another. It consists of *a bent tube, with arms of unequal length* (Figure 72). The air must be removed from the tube in the first place, either by applying the mouth to the end *B*, after the other arm of the siphon has been put into the vessel of water, or by filling the siphon with water before it is placed in the vessel. The water will flow through the siphon from *C* to *B* until the vessel is emptied, or until the level of the water falls below the mouth of the arm in the vessel.

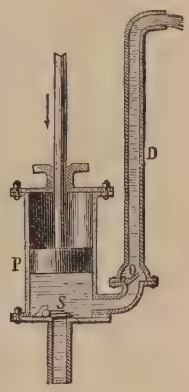


Fig. 71.

The flow of the liquid through the siphon seems opposed to the well-known fact that water will not run up hill; but it will be seen that the water is really flowing from a higher level *C* to a lower level *B*. If we consider the water in the siphon at *M*, we see that the force which acts upon it from left to right is equal to the pressure of the atmosphere *minus* the pressure of the water in the tube from *M* to *C*, whose depth is *D C*; and the pressure which acts upon it from right to left is equal to the pressure of the atmosphere *minus* the pressure of the water

in the tube from M to B, whose depth is AB. Since AB is greater than DC, the pressure at M towards the right will be greater than that towards the left. Consequently the water at M moves on towards B; and, as it moves away, more water is driven up into the arm CM to take its place, by the pressure of the atmosphere on the surface of the water in the vessel. No liquid will flow through a siphon unless the atmospheric pressure is sufficient to raise it to the bend of the tube.

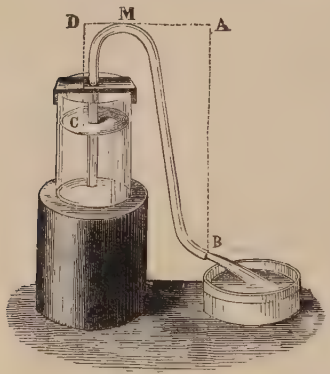


Fig. 72.

95. **Tantalus's Cup.** — This is *a glass cup with a siphon tube passing through the bottom*, as shown in Figure 73. If water is poured into the cup, it will rise both inside and outside the siphon, until it has reached the top of the tube, when it will begin to flow out. If the water runs into the cup less rapidly than the siphon carries it out, it will sink in the cup until the shorter arm no longer dips into the liquid, and the flow from the siphon ceases. The cup will then fill as before, and so on.

Fig. 73.

In many places there are *springs* which flow at

intervals, like the siphon in this experiment, and whose action may be explained in the same way. A cavity under ground (Figure 74) may be gradually filled with water by springs, and then emptied through an opening which forms *a natural siphon*. In some cases of this kind the flow stops and

Fig. 74.

begins again several times in an hour. Such springs are called *intermittent* springs.

96. **The Barometer.** — The *barometer* is an instrument for *measuring the pressure of the atmosphere*. In its ordinary form it is a Torricellian tube furnished with a convenient case (Figure 75). The vessel for the mercury at the bottom must be constructed so as to prevent the spilling of the mercury

in transportation, and so as to allow the atmosphere to act freely upon the mercury.

Fig. 75.

A change in the weather is generally attended with a change in the pressure of the atmosphere: hence *the rise and fall of the barometer often enable us to foretell the weather.* As a general rule, the *rising* of the mercury indicates the coming of *fair* weather, and its *falling* that of *foul* weather.

If we take a barometer up a mountain, the mercury will fall, because there is less weight of air pressing upon it. The higher we go, the lower will the mercury fall: hence *the barometer may be used to measure the height of mountains.*

Illustrations. — At the level of the sea the height of the column of mercury in the barometer is about thirty inches. As we go up from this level, the mercury falls *about* one inch for every nine hundred feet of perpendicular height. As the *density* of the air diminishes with the ascent, the fall of the mercury for a given difference of elevation will be less and less as we go higher and higher. The fall is also affected by the temperature. Tables, however, have been prepared, which enable us to get the height of a place above the level of the sea quite accurately by observing the fall of the barometer and the change in temperature.

QUESTIONS.

1. Give an illustration of the pressure of the atmosphere. 2. To what is the pressure of the atmosphere equal at the level of the sea? 3. What is true of it as we ascend? 4. Why? 5. To what height will water rise in an exhausted tube? 6. To what height will mercury rise? 7. What causes a liquid to rise in exhausted tubes and vessels? 8. Why will some liquids rise higher than others? 9. Give Torricelli's experiment. 10. What is the action in drinking lemonade through a straw? 11. In pumping water? 12. What are the names of the two kinds of pumps in ordinary use? 13. Why are they so named? 14. Where are the valves in each? 15. What takes place when the piston of each is raised and depressed? 16. What is a siphon? 17. For what is it used? 18. How is the flow started? 19. How long will it continue? 20. Explain why the liquid flows through the siphon. 21. Describe Tantalus's cup. 22. Describe its action. 23. What are intermittent springs? 24. What is a barometer? 25. Of what does it consist? 26. What are its two chief uses? 27. What is said of its use in measuring the height of mountains?

IV.

SOUND.

CHAPTER XIV.

ORIGIN AND NATURE OF SOUND.

97. **Origin of Sound.** — Every body which is emitting sound is in a state of vibration. When the vibration stops, the sound ceases. These vibrations are executed either by the body as a whole, or by sensible portions of the body: they are, therefore, *molar* vibrations (13). Sound originates in *molar vibrations of solids, liquids, or gases.*

Fig. 76.

Illustrations. — Fill a glass brimful of water, and strike a tuning-fork so as to cause it to emit a sound. Hold the edge of the prong of the fork in contact with the water: a shower of spray will fly off on each side, showing that the prongs are in vibration.

Pluck one of the strings of a violin so as to make it give a sound. On looking directly down upon the string, we see that it is in a state of vibration. It will have the appearance shown in Figure 76.

Lower a little stretched membrane covered with sand into an organ-pipe whose front is glass, as shown in Figure 77, while the pipe is emitting a sound. The sand will be seen to be agitated, showing that the air within the pipe is in a state of vibration.

Fig. 77.

98. **Fundamental and Harmonic Vibrations.** — By *fundamental* vibrations we mean the vibrations that are executed by a body as a whole; and by *harmonic* vibrations those which are executed by the parts, or *segments*, of the body. Figure 78 shows a string vibrating as a whole, and in two, three, and four segments. The harmonic vibrations are more rapid than the fundamental vibrations; and the smaller the vibrating segments the quicker are the vibrations.

Whenever the fundamental vibrations of a body are started, some of the harmonic vibrations are almost certain to be started with it: hence the molar vibrations which produce a sound are more or less complicated.

99. **Quality of Sound.** — The *quality* of a sound depends entirely upon the *character* of the vibrations which produce it; that is, on the number and

kind of the *harmonics* which are combined with the fundamental vibration. A rough, irregular sound is called a *noise;* and a smooth and regular one is called a *musical sound.*

Every change in the number, kind, or intensity of the harmonic vibrations present causes a change in the quality of the sound. One vowel sound or one musical tone differs from another simply because of some difference in the harmonic vibrations which produce it. Every articulate sound, as well as every musical tone, is produced by a particular combination of harmonic and fundamental vibrations; and whenever that particular kind of vibration is produced, no matter how, the particular sound which corresponds to it is heard. We shall see farther on that it is possible to produce articulate sounds and words by other means than the organs of speech.

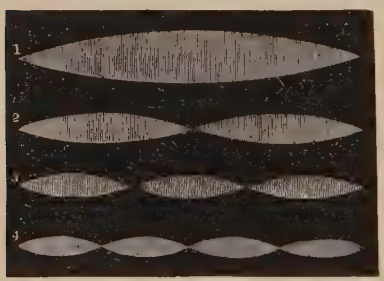


Fig. 78.

100. **Loudness and Pitch of Sound.** — The *loudness*, or *intensity*, of sound depends upon the *energy* of the vibrations. The *pitch* of sound depends upon the *rapidity* of the vibrations. Two sounds are said to be in *unison* when their rates of vibration are the same; and to form an *octave*, when their rates of vibration are as two to one.

Illustrations of Pitch. — In the lowest note of the organ, there are sixteen and a half vibrations a second. In the lowest note of the piano there are thirty-three vibrations a second, and in the highest note 4224, giving a range of seven octaves. In the highest note ever heard in an orchestra, there are 4752 vibrations a second. This note is given by the piccolo flute. In the shrillest sounds that are audible there are about 32,000 vibrations a second, the upper limit of audibility varying with different persons. The voice of ordinary chorus-singers ranges from a hundred to a thousand vibrations a second, and the extreme limits of the human voice are fifty and fifteen hundred vibrations a second.

101. **Stringed Instruments.** — In one class of musical instruments the notes are produced by *the transverse vibrations of strings.* These instruments are called *stringed* instruments. The *rate* at which a string vibrates depends upon its *length,* its *weight,* and its *tension.* The *shorter,* the *tighter,* and the *lighter,* a string, the *faster* it vibrates. Strings may be thrown into transverse vibration by drawing a rosined bow across them, as in the case of the violin; or by plucking them with the finger, as in the case of the harp; or by striking them with a hammer, as in the case of the piano.

Illustrations. — In the piano there is a string for every note. In the violin and similar instruments, several notes are obtained from the same string by fingering it so as to change its length and tension.

102. **Wind Instruments.** — In *wind* instruments the notes are produced by *the longitudinal vibrations of columns of air enclosed in pipes.* The *rate* of vibration depends upon the *length* of the column, and upon *whether the pipe is opened or closed.* The

shorter a column of air, the *faster* it vibrates; and the air in an *open* tube vibrates *twice as fast* as that in a *closed* pipe of the same length.

The air in the pipe of a wind instrument is thrown into vibration sometimes by the vibrations of the lips when the air is blown through them, as in the case of the trumpet; or by the vibration of a spring called a *reed* when the air is blown against it, as in the case of the clarinet; or by the flutter of a jet of air when blown against a sharp edge, as in the case of the flute.

Illustrations. — In an organ there are as many pipes as notes, only one note being obtained from each pipe. In the case of the flute and similar wind instruments, several notes are obtained from one pipe by opening and closing the holes at the side of the pipe so as to alter the length of the vibrating column of air, and by altering the strength of the blast so as to change from the fundamental note of the pipe to one or other of its harmonics.

QUESTIONS.

1. What is the condition of every sounding body? 2. In what does sound originate? 3. Give the illustration of the tuning-fork. 4. Of the violin-string. 5. Of the organ-pipe. 6. What do we mean by fundamental vibrations? 7. By harmonic vibrations? 8. What is true of the rate of these different vibrations? 9. Upon what does the quality of sound depend? 10. What is the difference between a noise and a musical sound? 11. What will cause a change in the quality of sound? 12. Why does one vowel sound or one musical tone differ from another? 13. By what is every articulate sound produced? 14. What follows when that particular kind of vibration is produced by any means whatever? 15. Upon what does the loudness of sound depend? 16. Upon what does the pitch of sound depend? 17. When are two sounds said to be in

unison? 18. To form an octave? 19. Give illustrations of range of pitch. 20. How are musical sounds produced in stringed instruments? 21. Upon what does the rate of vibration depend? 22. How are the strings thrown into vibration? 23. How do we obtain the different notes in a piano? 24. In a violin? 25. How are musical sounds produced in wind instruments? 26. Upon what does the rate of vibration depend? 27. How is the air in the pipe thrown into vibration? 28. How are the different notes obtained in the organ? 29. In the flute?

CHAPTER XV.

PROPAGATION OF SOUND AND SYMPATHETIC VIBRATIONS.

103. **Sound is Propagated by all Elastic Substances.** — Sound is not propagated in a vacuum, but is propagated by *all elastic substances*, whether solid, liquid, or gaseous. Sounds are propagated chiefly by the air.

Illustrations. — If a bell is hung in the middle of a glass receiver from which the air has been exhausted, as shown in Figure 79, no sound is heard when the bell is rung. If air, hydrogen, or any other gas, is now allowed to pass into the receiver, the sound of the bell is heard again. If a bell is put under water and struck, it can be heard. If a person puts his ear close to the rail of an iron fence, and the rail is struck at a considerable distance, he hears the blow twice. The first sound comes through the rail; the second, which soon follows, comes through the air.

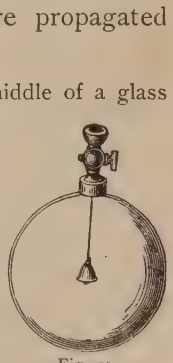


Fig. 79.

104. **Sound is Propagated by Waves.** — As a sounding body moves to and fro in the air, it starts

a series of *waves* in the air, in the same way that a board, when moved to and fro, would start a series of waves in water. These sound-waves traverse the air, spreading in every direction from the vibrating body. As they beat against the ear, they awaken in us a sensation of sound. The propagation of sound by means of waves is shown in Figure 80.

Were sound-waves visible, they would be seen to differ considerably from water-waves. The particles

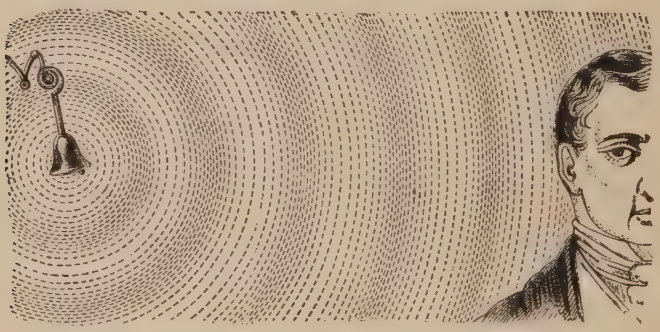


Fig. 80.

would be seen to vibrate to and fro in the direction in which the wave is advancing; that is, *longitudinally*, not *transversely*, or across the direction in which the wave is advancing, as in the case of water-waves. Instead of being alternately raised above, and depressed below, the general level, so as to form *crest* and *hollow*, as in the case of water-waves, the molecules in sound-waves are alternately crowded together and drawn apart, so as to form *compressed* and *rarefied* portions, or *phases*.

105. **Form of Sound-Waves.** — By the form of

a water-wave we mean the outline of the surface of the wave. By the form of a sound-wave we mean *the degree of condensation* or *rarefaction* in the two phases of the wave. Were the sound-wave visible, we should see that there was a special form of sound-wave corresponding to each variety of vibration of the sounding body. Each musical tone and each articulate sound would be seen to have its own wave-form, which would differ from every other wave-form. We should see that sounds of *high* pitch would have *short* waves, and those of *low* pitch *long* waves.

106. **The Velocity of Sound.** — Sound travels through the *air* at the rate of *ten hundred and ninety feet a second,* at the temperature of the freezing-point. This is at the rate of about a mile in five seconds.

The velocity of sound in air depends somewhat upon the state of the atmosphere. Sound-waves travel faster with the wind than against it; and the higher the temperature of the air, the greater the velocity of sound in it.

The velocity of sound in *water* is about *forty-seven hundred feet a second,* and its velocity in solids is still greater.

Illustrations. — When you see a person chopping at a distance, you can always see him strike some time before you hear the blow. When a cannon is fired at night a mile away from us, we can see the flash about five seconds before we hear the report. We see the flash of lightning before we hear the thunder. The nearer the lightning, the shorter is the interval between the flash and the thunder.

107. **The Reflection of Sound.** — When sound-waves meet the surface of a new medium, they are, in part, thrown back, or *reflected.* In this reflection, as in all cases of reflected motion (52), *the angles of incidence and reflection are equal to each other.*

Illustrations. — *Echoes* are produced by the reflection of sound. In order to get an echo, we must have a reflecting surface far enough away to give an appreciable interval between the direct and reflected sounds. When the surface is less than a hundred feet distant, the reflected sound blends with the direct sound.

The reflecting surface has often such a shape as to cause the different portions of the reflected wave to converge to a point, and so to intensify the reflected sound.

Multiple echoes may be produced by successive reflections from surfaces at different distances on the same side, or by alternate reflections from two surfaces on opposite sides. In some localities a pistol-shot is repeated thirty or forty times.

108. **Sympathetic Vibrations.** — Whenever sound-waves encounter a body which is capable of vibrating at the rate at which the waves follow each other, they throw it into vibration. Vibrations started in this way, by the pulsations of sound, are called *sympathetic vibrations.*

Each wave, as it meets the body, gives it a little push, and moves it forward a little way. The body is then released, and flies back; and the next wave meets it just in time to give it another push as the body is ready to start forward again of itself. Each wave pushes the body but little; but the pushes are so timed, that each moves it a little farther than the last, until the body is made to vibrate strongly.

When the body cannot vibrate at the rate at which the waves succeed each other, the waves will sometimes push the body in the direction in which it is moving of itself, and sometimes in the opposite direction. In this case, one push will neutralize the effect of another instead of augmenting it. It is like pushing a person who is swinging. A succession of pushes, rightly timed, may make a heavy person swing powerfully; while the same pushes, or even stronger pushes, wrongly timed, would not only fail to set one swinging, but stop one who was already swinging.

Illustrations. — Take two tuning-forks of exactly the same pitch; cause one of them to vibrate, and hold it near the other without touching it. The second fork will soon begin to vibrate, and will emit a distinctly audible sound after the first has been stopped. The second fork will not be started by the first unless the two are of exactly the same pitch, as may be shown by sticking a little pellet of wax to the prong of one of the forks, so as to diminish its rate of vibration.

If a piano is opened, and one of the keys gently depressed, so as to raise the damper without striking the string with the hammer, and the note of the string is then sung over the piano, the string will begin to vibrate, and will emit an audible sound for a little time after the voice ceases. It is only necessary to hit the pitch of a string accurately, and to sustain the note sufficiently.

If a vibrating tuning-fork is held at the end of a tube an inch and a half or two inches in diameter, the sound of the fork will be powerfully reinforced, if the tube is of suitable length. The suitable length for a tube open at both ends is one-half of the length of the wave produced by the fork. A tube closed at one end resounds most powerfully when its length is one-quarter of the length of the wave produced by the fork. The column of air in the tube is thrown into power-

ful sympathetic vibrations by the fork, and these vibrations greatly augment the sound. The moment the fork is stopped, the sympathetic sound ceases.

109. **Sympathetic Vibrations of Thin Membranes.** — Thin membranes, when stretched, are very readily thrown into sympathetic vibration; but their vibrations stop promptly when the exciting sound ceases. Owing to the facility with which they break up into vibrating segments, they respond readily to all rates of vibration. The same is true of thin metallic plates

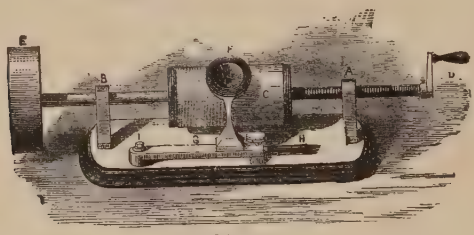


Fig. 81.

110. **Edison's Phonograph.** — Edison's *phonograph*, which is shown in Figure 81, consists of a cylinder *C*, and of a mouth-piece *F*. An enlarged view of the mouth-piece is shown in Figure 82. At the bottom of the conical opening of the mouth-piece is a thin metallic plate *A*. Under this plate is a point *P*, which is separated from the metallic plate by a piece of rubber tube *x*, against which it is held by the spring *E*. The cylinder is turned by the crank *D*. A screw cut in one end of the axis causes the cylinder to move along horizontally as it rotates. A shallow spiral groove is cut in the surface of the cylinder in such a way as to be

always under the point P as the cylinder is turned. A sheet of tin-foil is fastened smoothly on the surface of the cylinder. The point P presses against this tin-foil; and, if the metallic plate is not vibrating, this point will mark a spiral line of uniform depth on the tin-foil as the cylinder is turned. If we speak or sing into the mouth-piece, the plate A is thrown into sympathetic vibration; and the vibrations of this plate are exactly like those which produce the articulate sounds of the words spoken. The point P follows the centre of the plate in its vibration. If

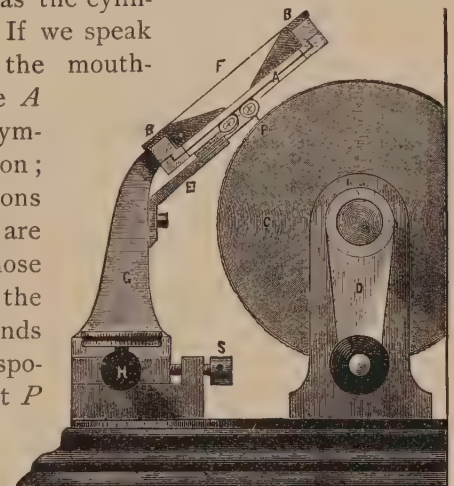


Fig. 82.

the cylinder is turned while one is speaking into the mouth-piece, the point will mark a line on the foil of varying depth, the depth of the indentations corresponding exactly to the vibrations of the point and of the plate. In this way, the vibrations of the plate are registered on the sheet of tin-foil. Now, pull back the mouth-piece, set the cylinder back to the starting-point, replace the mouth-piece, and again turn the cylinder. As the indentations of the tin-foil pass under the point, they compel it

to move to and fro exactly as it did in producing them, and the point, in turn, compels the plate to vibrate exactly as it did at first, and therefore to repeat the words that were spoken to it. This may be repeated several times, and the words may be distinctly heard by all in the room.

QUESTIONS.

1. By what substances is sound propagated? 2. By what is it chiefly propagated? 3. Give an illustration to show that sound is not propagated in a vacuum. 4. That it is propagated by any gas. 5. By a liquid. 6. By a solid. 7. In what way is sound propagated? 8. How are these waves started? 9. How do the vibrations in sound-waves differ from those of water-waves? 10. What are the two phases of sound-waves? 11. What is meant by the form of a water-wave? 12. By the form of a sound-wave? 13. What is true of the wave-form for each musical tone and for each articulate sound? 14. What waves have sounds of high pitch and low pitch? 15. What is the velocity of sound in air? 16. In water? 17. In solids? 18. Give illustrations of the velocity of sound in the air? 19. What is meant by the reflection of sound? 20. What law of reflected motion applies here? 21. Explain the production of echoes. 22. In what two ways may multiple echoes be produced? 23. What are sympathetic vibrations? 24. Explain how these vibrations are produced. 25. Why are no vibrations started in a body which is not capable of vibrating at the rate at which the waves follow each other? 26. Give the illustration of sympathetic vibrations in the case of the tuning-fork. 27. In the case of the piano-string. 28. In the case of tubes. 29. In the case of thin membranes. 30. Describe Edison's phonograph. 31. Describe the vibrations of the plate and of the point. 32. Explain how the vibrations are registered on the tin-foil. 33. Explain how the plate may again be made to vibrate so as to repeat the words that have been spoken to it.

V.

HEAT.

CHAPTER XVI.

NATURE AND TRANSMISSION OF HEAT.

111. **Nature of Heat.** — Heat originates in the *molecular and atomic vibrations* of bodies. The atoms and molecules of bodies are in a state of constant agitation, vibrating to and fro with very great rapidity; and the hotter the body, the more lively is this movement. A body feels hot when we touch it, because its molecules and atoms are beating with such rapidity and vigor against the skin. Any thing that will increase the agitation of the molecules of a body will make it hotter.

Illustrations. — When we rub a match against a rough surface, the friction increases the agitation of the molecules, and so heats the end of the match enough to light the phosphorus on it. A brass button rubbed against the sleeve becomes hot for a similar reason. Friction always develops heat. A blacksmith may heat an iron nail red-hot by striking it vigorous and rapid blows with a hammer. Every blow upon the nail increases the agitation of its molecules and atoms. In the burning of a piece of coal, the atoms of oxygen in the air and those of the coal rush together with inconceivable rapidity,

and as they dash against one another they are thrown into intense vibration: hence the heat developed in this and other cases of combustion.

112. **Radiation of Heat.** — As the atoms of a body move to and fro in the ether (18), they start waves in the ether in the same manner that a stick moved rapidly to and fro in water will start waves in the water. These ethereal waves are exceedingly minute, from thirty to sixty thousand of them being required to make an inch when placed end to end; and they traverse the ether with a velocity which would carry them more than seven times around the earth in a second. By means of these waves the heat of a body becomes distributed through space. This method of distributing heat is called *radiation*. The body in which the waves are started is said to *radiate* heat. Rough and blackened surfaces radiate heat better than bright and polished ones.

Illustrations. — The heat which we feel when we are near a stove or other hot body comes to us chiefly by radiation. The heat of the sun comes entirely by radiation. Stoves are better radiators for having black and rough surfaces. Water will keep hot longer in a bright polished teapot than in a rough iron kettle.

113. **Absorption of Heat.** — When the ethereal waves beat against the atoms of a second body, they throw these atoms into vibration, or else increase their agitation, and thus communicate heat to them. The heat taken up in this way by the atoms of a body is said to be *absorbed* by the body. The best radiators are also the best absorbers.

114. Conduction of Heat. — If one end of an iron poker is placed in the fire, the heat will be found to travel slowly along the poker till its farther end finally becomes hot. This slow transmission of heat through a body, from molecule to molecule, is called *conduction.* The metals are *good conductors* of heat: glass, wood, straw, wool, liquids, and gases, are *poor conductors* of heat.

Illustrations. — One end of a glass rod may be held in the flame of a spirit-lamp till it is heated white-hot; and yet an inch away from the red-hot portion the glass scarcely feels warm. The soldering irons used by plumbers are provided with wooden handles, to keep them from allowing the heat to pass to the hand. A thin pane of glass is sufficient to keep the heat from escaping from a room. A covering of straw is an excellent protection to plants, because it conducts the heat away from them so slowly. A piece of cold iron feels much colder than a fleece of wool or a piece of flannel at the same temperature, because it conducts the heat away from the hand so rapidly. Hair and feathers are excellent protection for animals and birds, because they serve to keep the same layer of air in contact with the skin, and the air is a very poor conductor of heat.

Fig. 83.

Experiments. — The different conducting powers of different solids may be shown by the following experiment: two rods, of different materials, are placed near together, end to end, as shown in Figure 83. Little balls are stuck, at equal intervals, to these rods with wax. The ends of both rods are then exposed to the same source of heat. As the heat passes along the rods, the wax is melted, and the balls drop. The rod from which the balls drop the faster is the better conductor of heat.

To show the poor conducting power of water, put a piece of ice at the bottom of a test-tube, and nearly fill the tube with water. Place a lamp at the middle of the tube, as shown in Figure 84. The water will boil in the top of the tube, while the ice will not melt at the bottom.

Fig. 84.

115. **Convection.** — If heat is applied at the bottom of a liquid or gas, the portions of the fluid in contact with the heat become lighter, and rise, while the colder and heavier fluid on every side comes around to the heat to take the place of the portions which have passed off. In this way, currents are established, which distribute the heat by carrying it away with them. This method of distribution of heat is called *convection*, and the currents by which it is distributed are called *convection currents*. Liquids and gases are heated mainly by convection. The fluid rises over the centre of the heated portion, flows away from this centre in every direction

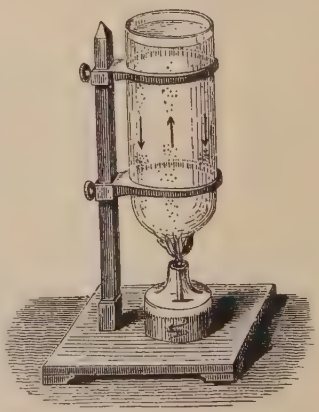


Fig. 85.

above, flows down on all sides around the ascending column, and flows in towards the source of heat from every side below.

Illustrations. — When heat is applied to the bottom of a glass vessel filled with water which holds small particles in suspension, the currents will be seen to flow in the directions indicated by the arrows in Figure 85.

If a door into a warm room is left a little ajar, and a lighted candle is held at the top, middle, and bottom of the door, the flame of the candle will be seen to be blown outward at the top, and inward at the bottom, while it will remain steady at the middle. The air attempts to escape from every side at the top of a heated room, and to enter from every side at the bottom. It is mainly by the air entering and escaping through the cracks at the doors and windows that the room becomes ventilated.

Winds are convection currents on a large scale in the atmosphere. Portions of the atmosphere become excessively heated by contact with the earth, or by other means, and so start these currents.

QUESTIONS.

1. In what does heat originate? 2. What takes place when a body is heated? 3. Why does a body feel hot? 4. What will make a body hotter? 5. Give three illustrations. 6. What do the vibrating atoms start in the ether? 7. Describe these waves. 8. What do these waves do? 9. What do we mean by the radiation of heat? 10. What kind of surfaces are good radiators? 11. Give illustrations of the radiation of heat. 12. How do bodies absorb heat? 13. What bodies are the best absorbers? 14. What do we mean by the conduction of heat? 15. Give an illustration. 16. Name some substances which are good, and some which are poor conductors. 17. Why have soldering irons wooden handles? 18. Why will a thin pane of glass keep out the cold? 19. What material makes a good winter covering for plants? 20. Why? 21. Why

does a piece of iron feel colder than wool? 22. Why are feathers and fur so good a protection against cold? 23. Give an experiment which shows the unequal conducting power of different solids. 24. Give an experiment which shows the poor conducting power of liquids. 25. What is meant by the convection of heat? 26. Describe convection currents, and tell how they are started. 27. Describe the convection currents formed in heating water. 28. Describe the convection currents in the case of a heated room. 29. Describe an experiment which will show the existence of these currents. 30. What are the winds? 31. How are they started?

CHAPTER XVII.

THE THREE EFFECTS OF HEAT.

116. **Expansion.** — An almost universal effect of heat, when imparted to bodies, is to cause them to become larger, or to *expand* them. Heat expands bodies by causing their molecules to separate from each other. Gases expand more than liquids, and liquids more than solids, for the same rise of temperature. Different solids and liquids expand unequally when heated equally, but all gases expand alike. The expansive power of a solid when heated is almost irresistible. A rod of iron an inch square, when heated from 32° to 212°, exerts an expansive power of about fifteen tons in the direction of its length.

Illustrations. — In all structures in which metals are employed, the parts must be arranged in such a way that the expansion shall not be attended with evil effects. In a railway, the rails are not placed in contact, but left a little apart to allow room for variation of length. Iron beams employed in

building must have their ends free to move without encountering obstacles, which they would inevitably overthrow.

Experiments. — The expansion of a *solid* when heated may be illustrated by means of the ring and ball shown in Figure 86. When cool, the ball passes readily through the ring; but when heated it will rest upon the ring, as shown in the figure, without falling through.

The expansion of a *liquid* when heated may be illustrated by means of a glass bulb with a projecting tube, as shown in Figure 87. The bulb and a part of the tube are filled with the liquid to be tried. The bulb is then heated by immersing

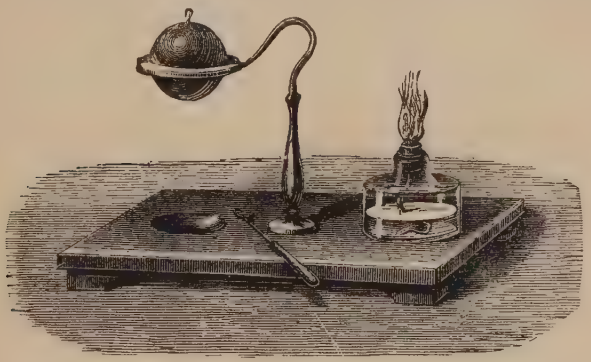


Fig. 86.

it in hot water. At first the liquid falls a little in the stem, owing to the fact that the bulb itself becomes heated and expands before the liquid in it begins to expand. Soon, however, the liquid begins to rise in the stem.

The expansion of a *gas* may be illustrated by means of a bulb with a long projecting tube, as shown in Figure 88. If we heat the bulb by grasping it in the hand, the little column, or *index*, of mercury, *m*, is seen to move forward, showing that the air in the bulb has expanded. The index of mercury is introduced into the tube in the first place by heating the bulb, so as to drive out some of the air by expansion. A little mercury is then dropped into the cup *a*, and the bulb allowed to cool. As the bulb cools, the air in it contracts,

and the mercury is forced into the tube by the pressure of the external air.

117. **Irregular Expansion and Contraction of Water.** — As water cools, it contracts, like every other liquid, until it reaches a temperature of about 39°. It then begins to expand, and expands slowly, till its temperature reaches 32°. It then freezes, and expands considerably in freezing. After it has frozen, it begins to contract again as its temperature falls. Were the temperature of ice raised, it would expand till it reached 32°. It would then contract considerably on melting, and continue to contract slowly, till the temperature was about 39°; it would then expand again.

Fig. 87.

Fig. 88.

Illustrations. — Since water is most dense at a temperature of about 39°, it begins to grow lighter, and to rise to the surface before it gets cold enough to freeze. The consequence is that water begins to freeze at the surface instead of at the bottom; and the layer of ice at the surface, being a poor conductor of heat, prevents the water from freezing to any great depth, unless the cold is excessive and of long continuance. It is because of its expansion in freezing, that water is liable to burst the pipes and vessels in which it is allowed to freeze.

118. **Change of State.** — A second effect of heat is to *change the state* of a body. A solid, when heated to a sufficient temperature, *melts*, and becomes a liquid; and a liquid, when heated to a sufficiently high temperature, *boils*, and becomes a gas or vapor. The temperature at which a solid melts is called its *melting-point* or *fusing-point;* and the temperature at which a liquid boils is called its *boiling-point.* The melting-point of ice is 32°, and the boiling-point of water is 212°.

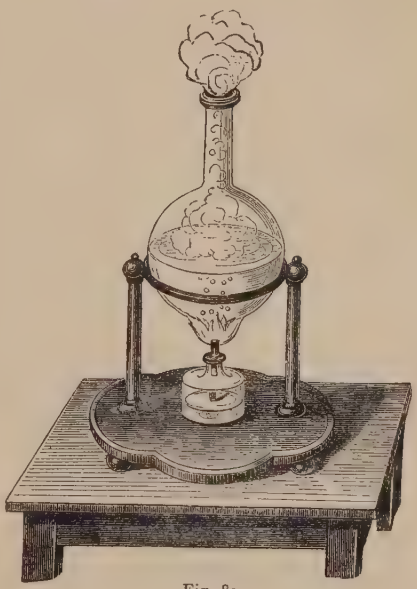


Fig. 89.

119. **Evaporation.** — A liquid like water evaporates at all temperatures, but more rapidly as the temperature rises. The evaporation of water is more rapid when the air is dry than when it is moist. It is also more rapid on a windy day than on a still day. At temperatures below the boiling-point, the evaporation takes place only at the surface of the liquid; while at the boiling-point, it takes place throughout the liquid.

Illustrations.—Water which is exposed to the air in a dish gradually disappears, because it evaporates, and passes into the atmosphere as invisible vapor. Wet surfaces soon dry, owing to the evaporation of the water on them. Clothes will dry much faster on a windy day than on a still day, because the wind promotes the evaporation. A wet slate will dry quicker if we fan it, or swing it to and fro in the air. A barrel of water will evaporate much quicker when sprinkled on the pavements than when left in the barrel, because it exposes a greater surface from which evaporation can take place.

Fig. 90.

Experiment.— If water is heated in a glass flask, the vapor will at first rise only from the surface of the water; but it will be seen to escape faster and faster as the temperature rises. When the boiling-point is reached, bubbles of vapor will be seen to rise through the liquid, as shown in Figure 89, and to burst on reaching the surface. The upper part of the flask will now be filled with invisible vapor, which condenses into a mist as it comes in contact with the colder air at the mouth of the flask.

120. **Rise of Temperature.**— A third effect of the communication of heat to a body is to *cause its temperature to rise.* By the *temperature* of a body we mean its *power of imparting heat to other bodies.* The greater this power of imparting heat, the higher is the temperature of a body. A portion of the heat is employed in pushing the molecules into new positions. It is this portion

which causes expansion and change of state. Another portion causes the atoms and molecules to vibrate with greater rapidity. It is this portion which raises the temperature of the body. The temperature of a body is independent of the amount of heat in it.

A *unit of heat* is the amount of heat required to *raise one pound of water one degree* in temperature; and *specific heat* is the amount of heat required to raise *one pound of a given substance one degree* in temperature. Different substances differ greatly in their specific heat.

Illustrations. — It takes about ten times as much heat to raise a pound of water one degree in temperature as a pound of iron, and over thirty times as much as to raise a pound of mercury one degree.

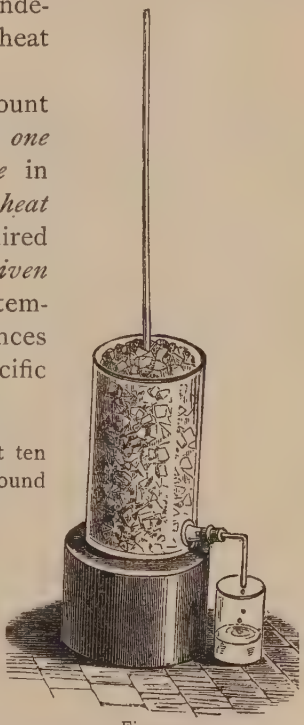


Fig. 91.

121. **Thermometers.** — A *thermometer* is an instrument for *measuring temperature.* The ordinary thermometer consists of a glass tube of very fine bore, with a bulb blown in one end of it. The bulb and a part of the tube are filled with mercury. As the temperature of the bulb rises, the mercury expands, and rises

in the tube. When the temperature falls, the mercury contracts, and falls in the tube.

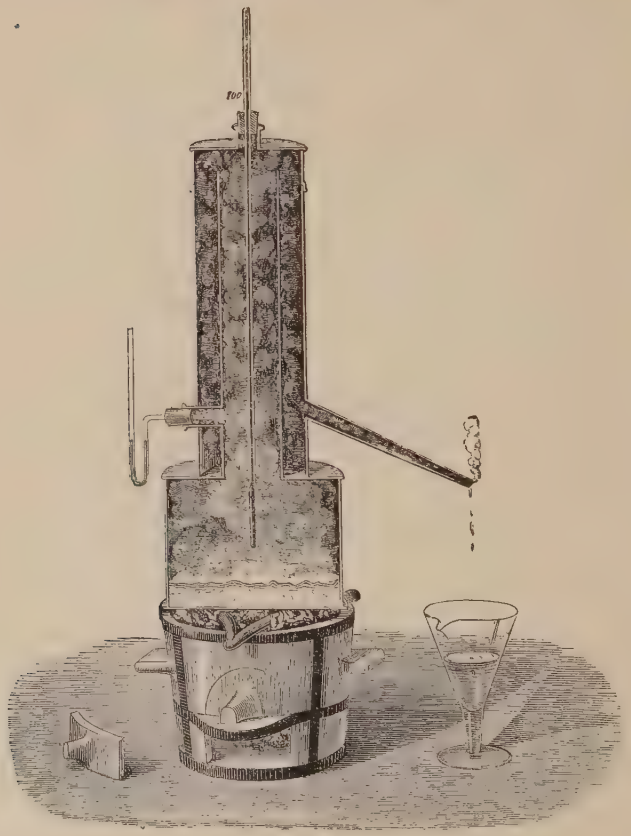


Fig. 92.

How a Thermometer is Filled. — The opening in the tube of a thermometer is too fine to allow mercury to be poured into it. In filling the instrument, a little cup is formed at the open end of the stem, and filled with mercury, as shown in

Figure 90. The bulb is heated, and a part of the air is driven out through the mercury by expansion. The bulb is then allowed to cool. The air in it contracts, and some of the mercury from the cup falls into the bulb. The bulb is again heated, and the mercury in it boiled for some time. The vapor of the mercury drives all the air out of the bulb and tube. The bulb is then again cooled, the vapor in it condenses, and the mercury from the cup falls into the tube and bulb, and completely fills them. The bulb is now heated up to the highest temperature the thermometer is intended to measure, so as to expel a part of the mercury; and the top of the tube is melted off, so as to close it. As the bulb cools the third time, the mercury contracts, and leaves an empty space in the upper part of the tube.

To obtain the freezing-point, the bulb of the thermometer is placed in melting ice, as shown in Figure 91, and the top of the column of mercury is marked on the stem. To obtain the boiling-point, the bulb and a portion of the stem are immersed in steam from boiling water, as shown in Figure 92.

QUESTIONS.

1. What is the first effect of heat on bodies? 2. What takes place in expansion? 3. What is said of the expansion of the different states of matter? 4. Of the expansive power of iron? 5. What precaution must be taken when metals are used in structures? 6. Give illustrations. 7. Give an experiment illustrating the expansion of solids. 8. Of liquids. 9. Of gases. 10. Describe the expansion and contraction of water. 11. What changes of state are effected by heat? 12. What do we mean by the melting-point? 13. By the boiling-point? 14. What is the melting-point of ice? 15. The boiling-point of water? 16. What is said of the evaporation of water? 17. Give illustrations. 18. Describe the experiment of boiling water. 19. What is a third effect of heat? 20. What do we mean by temperature? 21. In what two ways is the heat communicated to a body employed? 22. What is a unit of heat? 23. What do we mean by specific heat?

24. Give illustrations of difference of specific heat. 25. What is a thermometer? 26. Explain how it shows changes of temperature. 27. Describe the filling of the thermometer. 28. Explain how the freezing and boiling points are found.

CHAPTER XVIII.

LATENT HEAT.

122. **Latent Heat.** — The heat that is employed in *maintaining the temperature* of a body is called *sensible heat;* while that which is employed in *expanding* the body, or in *changing its state*, is called *latent heat.* Whenever a body is expanded, or a solid is melted, or a liquid is evaporated, the molecules are pushed into new positions, or put into positions of advantage (56). Latent heat is therefore molecular energy of *position*, or a kind of *potential* energy. Sensible heat is, on the other hand, molecular energy of *motion*, or a kind of *kinetic* energy.

123. **Heat Consumed in Expansion.** — Whenever a portion of matter *expands*, heat is *consumed*, or *rendered latent.* When a gas expands without being heated, a portion of the sensible heat in it is converted into latent heat, and the temperature falls. The heat thus consumed is called the *latent heat of expansion.* When the gas is again compressed, its latent heat is again converted into sensible heat, and its temperature rises.

Experiment. — Let a receiver which has a thermometer passing into it through the top be placed upon the plate of

an air-pump. If we now work the pump, the air in the receiver expands, and the mercury falls in the thermometer. The fall of the mercury shows that the air becomes chilled by the expansion. If the air in the receiver is moist, a slight cloud will be seen to form in the receiver soon after the exhaustion begins. The chilling of the air by expansion causes some of its moisture to condense.

Illustrations. — Were a cubic foot of air suddenly raised from the surface of the earth two miles into the atmosphere, it would expand very much, because the air around it would exert less pressure upon it. The expansion, in this case, would cause the temperature to fall about 35°. One reason why it is so cold in the upper regions of the atmosphere is that the heated air which rises from the surface becomes chilled by expansion.

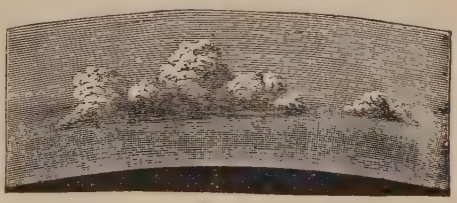


Fig. 93.

The chilling of the air in the above case would cause most of the vapor in the air to condense, so as to form a cloud or rain. Clouds and rain are caused chiefly by the chilling of ascending currents of air because of their expansion. Figure 93 shows clouds that are formed on the top of ascending columns of air.

124. **Heat Consumed in Liquefaction.** — Heat is consumed, or rendered latent, whenever a solid is *liquefied.* The heat thus consumed is called the *latent heat of liquefaction,* or *of the liquid* formed. It takes 143 units of heat to melt a pound of ice without raising the temperature at all. The latent heat of water is therefore 143. When a liquid solidifies, its latent heat again becomes sensible.

Experiments. — Hang up a piece of ice in a warm room over a dish which will catch the water dripping from it. If we apply the bulb of a thermometer to the ice, it will be found to maintain a temperature of 32° till it is all melted. If we allow the water which drips from the ice to fall upon the bulb of a thermometer, the temperature of the liquid will also be found to be 32°. The ice is all the time receiving heat, but its temperature is not raised. All the heat is used in melting the ice, and is therefore rendered latent.

Fill a small beaker-glass half full of pulverized nitrate of ammonia, and set it on a piece of wet board. Pour into it about an equal bulk of water, and stir the mixture with the bulb of a thermometer. The temperature will quickly fall to 18° or 20° above zero, and in half a minute the beaker will be frozen to the wet board.

Illustrations. — Ice-cream is frozen by means of a mixture of salt and ice. The salt causes some of the ice to melt, and the heat thus consumed lowers the temperature of the mixture below the freezing-point of the cream.

In the spring of the year a large amount of heat is consumed in melting the snow and ice, without raising the temperature: this retards the approach of hot weather. In the fall of the year an equally large amount of heat is given out in the formation of the snow and ice, without any lowering of the temperature: this retards the approach of cold weather.

125. **Heat Consumed in Evaporation.** — Whenever a liquid *evaporates*, heat is consumed, or rendered latent. This heat is called the *latent heat of evaporation*, or *of the vapor* formed. It takes nearly 1000 units of heat to convert a pound of water into vapor: hence the latent heat of watery vapor is about 1000. When a vapor condenses, its latent heat again becomes sensible.

Illustrations. — Dip the bulb of a thermometer into alcohol or ether. A film of the liquid will stick to the bulb when it

is withdrawn, and this film will quickly evaporate. This evaporation will cool the bulb several degrees, as will be shown by the fall of the mercury in the stem.

No matter how hot the fire is, the water in a kettle cannot be heated above 212°. When the temperature reaches that point, all the heat received by the water is used in converting it into vapor, and is therefore rendered latent.

Fanning cools a person chiefly because it promotes evaporation from the face.

QUESTIONS.

1. What is meant by sensible heat? 2. By latent heat? 3. What kind of energy is each? 4. What always takes place when a body expands? 5. What do we call this heat? 6. What is true of the temperature of a gas which expands without being heated? 7. Why? 8. What takes place when the gas is again compressed? 9. Describe an experiment which shows the consumption of heat by expansion. 10. Explain the formation of the cloud which is sometimes seen in this experiment. 11. How much would the temperature of a cubic foot of air fall if it were suddenly carried up two miles into the atmosphere? 12. Why would it fall? 13. Why would a cloud be formed? 14. What is the chief cause of the formation of clouds and rain? 15. What takes place when a solid is liquefied? 16. What name is given to this heat? 17. What is the latent heat of water? 18. What takes place when a liquid solidifies? 19. Give the experiment of the melting of a piece of ice. 20. Of the nitrate of ammonia and water. 21. Explain how ice-cream is frozen. 22. What retards the approach of warm weather in the spring, and of cold weather in the fall? 23. What takes place when a liquid evaporates? 24. What name is given to this heat? 25. What is the latent heat of steam? 26. Give the illustration of the evaporation of ether and alcohol. 27. What is the highest temperature to which water in an open vessel can be raised? 28. Why? 29. What is one reason why fanning cools the face?

VI.

LIGHT.

CHAPTER XIX.

NATURE AND TRANSMISSION OF LIGHT.

126. **Nature and Transmission of Light.** — Light, like radiant heat, originates in the *vibrations of the atoms* of a body, which start minute *waves in the ether*. These waves are in every way similar to those of heat, and they traverse the ether at the same rate. Light is therefore a kind of *molecular energy*. When these minute waves enter the eye, and beat upon the fibres of the optic nerve, they awaken the sensation of light. A single line of light is called a *ray*, and a collection of parallel rays is called a *beam*. A body which emits light of its own is called a *luminous* body. A body like glass, that will let light pass through it, is said to be *transparent;* and one like iron, which will not let light pass through it, *opaque*.

127. **Light Moves in Straight Lines.** — Light passes through a uniform medium *in straight lines*.

Illustrations. — Allow a beam of sunlight to enter a darkened room through a hole in the shutter. Its path across the room is seen to be a straight line.

When the sun shines into a room through a small opening, it always forms a round spot of light on the floor or wall, as shown in Figure 94. This is owing to the fact that the rays travel in straight lines, as shown in the figure. It will be seen that the rays coming from the various parts of the sun cross each other on passing through the opening: hence the picture on the floor is that of the sun inverted.

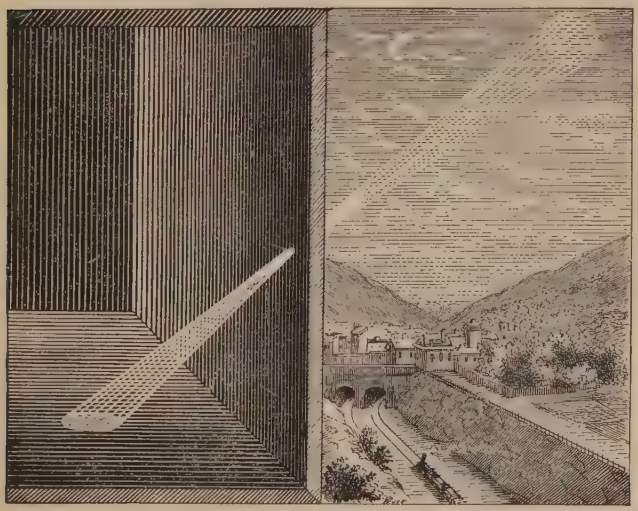


Fig. 94.

Allow light to enter a darkened room through a small opening in a shutter, and place a screen near the opening. An inverted and distinct picture of the objects without will be formed upon the screen, as shown in Figure 95. This picture is formed by the rays of light from the objects without, which pass through the opening. The picture is inverted: because, the rays of light being straight, those which come

from the top of an object will fall lower down on the screen than those which come from the bottom of the object. The picture is clear; because, the opening being small, only the rays from one part of the object can fall upon any one part of the screen. Were the opening large, the rays from several parts of the object would fall upon the same part of the screen, and the picture would become blurred; just as a painting would become blurred and indistinct, if the artist were to paint several parts of an object in the same place.

Fig. 95.

When any opaque body, as a sphere (Figure 96), is placed in front of a luminous point, it cuts off the light from the space behind it. The space thus deprived of light is called the *shadow* of the body. This shadow lies between straight lines which proceed from the point, and just graze the edge of the ball. The shadow is due to the fact that light moves in straight lines. A line drawn through the centre of the shadow, in the direction of its length, is called the *axis* of the shadow. If a screen is held at right angles to the axis

of the shadow, the outline of the shadow thrown upon it will be seen to be the same as that of the object which cast the shadow.

128. **Reflection.** — When a ray of light falls upon a smooth surface, it is in part thrown off, or *reflected.* The ray which falls upon the surface is called the *incident* ray, and the ray which is thrown back from the surface the *reflected* ray. The angle between the incident ray and a perpendicular drawn to the surface at the point at which the ray strikes it, is called the *angle of incidence;* and the angle between the reflected ray and this perpendicular, the *angle of reflection.* In the reflection of light, *the angles of incidence and of reflection are always equal to each other* (152).

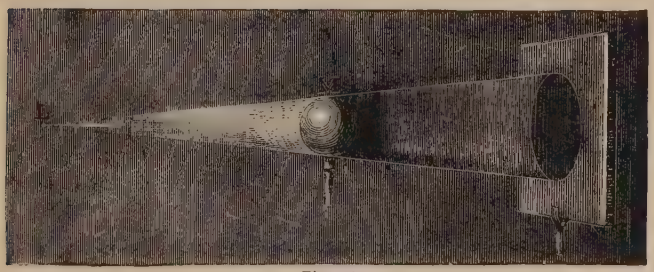


Fig. 96.

Illustration. — Place a small reflector upon a table in a darkened room, so that a beam of sunlight admitted through a hole in the shutter may fall upon it, as shown in Figure 97. The beam will be seen to be reflected in such a way that the angles of incidence and of reflection will be equal. Tilt the reflector so as to change the angle of incidence, and the angle of reflection will change equally.

129. **Refraction.** — When a ray of light passes

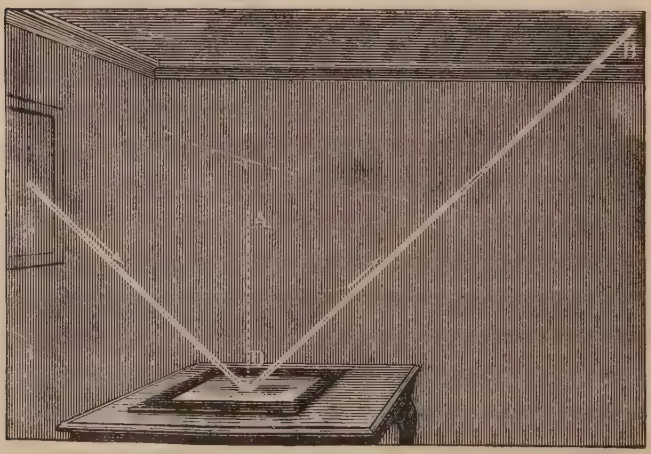


Fig. 97.

obliquely into a denser medium, it is bent, or

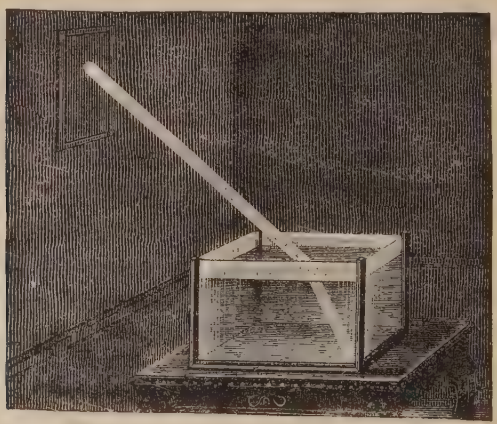


Fig. 98.

refracted, towards a perpendicular to the surface of

the medium, at the point where the ray strikes the medium; and, when the ray passes into a rarer medium, the ray is refracted in the opposite direction.

Illustrations. — Allow a beam of light, entering by the shutter into a darkened room, to fall upon the surface of water contained in a glass tank, as shown in Figure 98. The beam will be seen to be bent as it enters the water. A little

Fig. 99.

milk added to the water will make the path of the ray in the water much more distinct.

A fish or other object in water will be seen a little above its real position, as shown in Figure 99. The light which comes from the fish is bent, on passing into the air, away from a perpendicular to the surface of the water.

For a similar reason a stick held obliquely in water appears bent upwards, as shown in Figure 100.

130. **Dispersion.** — When a ray of white light passes through a prism, it is separated into seven

different colored rays, because these different rays are *bent unequally*. The red is bent the least, and the violet most. The seven colors obtained are *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*. This separation of the ray into its component colors is called *dispersion*. The seven colors thus obtained are called the *prismatic* colors, and the colored band formed on the screen by the rays after dispersion is called the *spectrum*. The *color* of a ray is due to the *length* of its ethereal waves. These waves are longest in red light, and

Fig. 100.

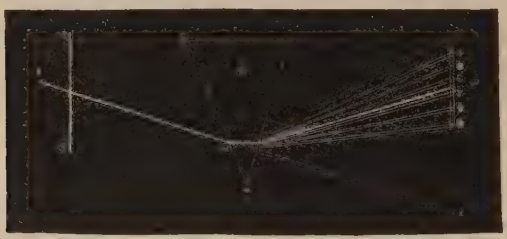


Fig. 101.

shortest in violet. *Refrangibility* in light corresponds to *pitch* in sound.

Illustrations.— Place a glass prism GEF (Figure 101) in the path of a beam of light, AB, admitted into a darkened room through a narrow hole in the shutter, SS'. The beam

will be both refracted and dispersed, as shown in the figure. There will appear on the wall a long colored band, red at the bottom and violet at the top.

131. **Diffusion.** — A portion of the light which falls upon the surface of a body is scattered irregularly in all directions. The light thus *irregularly*

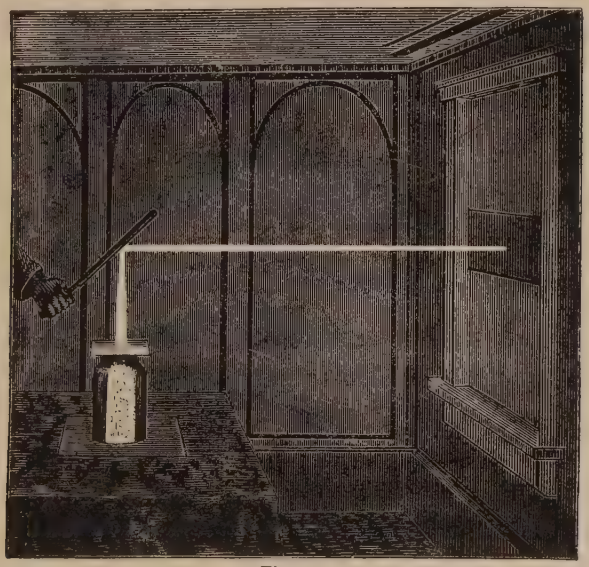


Fig. 102.

reflected is said to be *diffused.* It is by the light which they diffuse that we are enabled to see the surface of non-luminous bodies.

Illustrations. — Hold a small reflector in the path of a beam of light admitted into a darkened room, so as to reflect it into a glass vessel (Figure 102) through a narrow opening in a card laid on the top of the vessel. If the vessel is empty, the beam of light is invisible in the vessel If the

vessel is filled with smoke, the path of the beam becomes very bright, owing to the light diffused by the particles of the smoke which lie in the path of the beam. Reflect the beam of light into a goblet of water to which has been added a teaspoonful of milk. The liquid will shine like a lamp on account of the light diffused by the particles of milk suspended in the water.

132. **Absorption.** — A portion of the light which falls upon a body is *taken up and retained* by the body. This light is said to be *absorbed.* A body which absorbs some of the colors in preference to others will diffuse light in which these absorbed colors are wanting, or deficient. Such light will appear *colored,* its hue depending upon the kind of light which has been absorbed. The color of a non-luminous body is obtained from the light which falls upon it, the hue being produced by the extinction of some of the component colors by absorption. A body has no color in the dark. A rose is red, because it absorbs all the rays but the red; and a violet is violet, because it absorbs all the rays but those which make violet.

QUESTIONS.

1. In what does light originate? 2. How is it transmitted? 3. How is a sensation of light awakened? 4. What is light? 5. What is meant by a ray of light? 6. By a beam of light? 7. In what paths do rays of light move in a uniform medium? 8. Give the illustration of a beam of sunlight in a darkened room. 9. Of the spot painted by the sun on shining through a small opening. 10. Of images formed by small openings. 11. Why is such an image clear? 12. Why is it inverted? 13. Give the illustration of the formation of shadows. 14. What is meant by the axis of a shadow?

15. What is the outline of a shadow cast upon a screen perpendicular to the axis? 16. Why? 17. What is meant by reflection of light? 18. By the incident ray? 19. By the reflected ray? 20. By the angle of incidence? 21. By the angle of reflection? 22. What is the law of reflection? 23. Give an illustration of reflection. 24. What is meant by refraction of light? 25. Give the illustration of refraction in the tank of water. 26. In the case of the fish in water. 27. Of a stick in water. 28. What is meant by the dispersion of light? 29. Name the prismatic colors. 30. What is meant by the spectrum? 31. Upon what does the color of a ray depend? 32. To what does refrangibility in light correspond? 33. What is meant by diffusion of light? 34. Give the illustration of the jar of smoke. 35. Of the glass of milk and water. 36. What is meant by absorption of light? 37. What non-luminous bodies are colored? 38. To what is the hue of the color due? 39. Whence do bodies obtain their color? 40. Why do different bodies have different colors?

CHAPTER XX.

MIRRORS.

133. **Kinds of Mirrors.** — A reflector is often called a *mirror*. Mirrors are sometimes pieces of polished metal, sometimes pieces of glass coated in front with polished silver, and sometimes pieces of glass coated on the back with a mixture of tin and mercury, as in the case of the ordinary looking-glass. Mirrors with a flat surface are called *plane* mirrors; those with a concave surface, *concave* mirrors; and those with a convex surface, *convex* mirrors.

134. **The Visual Angle.** — The *visual angle* of an object, or of any portion of an object, is the

angle subtended by the object, or by that portion of it; that is to say, it is the angle *formed by lines drawn from the extremities* of the object, or the portion of it which we are considering, to the

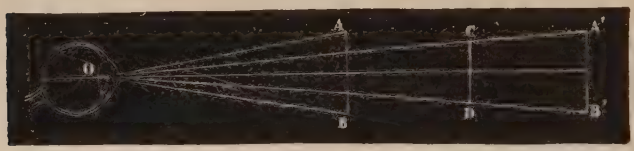


Fig. 103.

eye, as shown in Figure 103. The visual angle might be defined as the angle formed by *rays coming from the extremities* of the object to the eye. The nearer an object, the larger its visual angle; and, the larger an object (the distance being

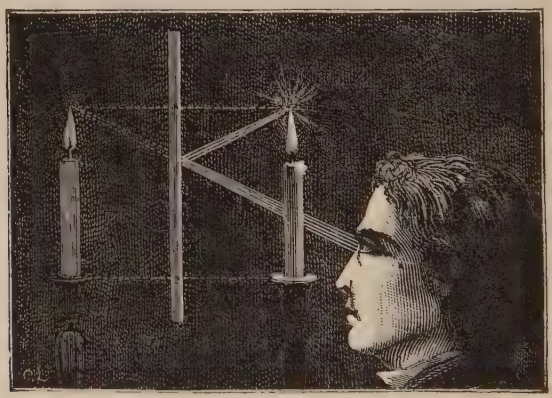


Fig. 104.

the same), the larger the visual angle. Any thing that increases the angle under which it is seen enlarges, or *magnifies*, the object; and any thing which lessens the visual angle makes the object appear *smaller*.

135. **Reflection from Plane Mirrors.** — When light is reflected from a plane surface, neither the divergency of the rays nor the visual angle is changed. Every portion of an object seen reflected in a plane mirror appears to be just as far *behind* the mirror as it really is in front of it. The reflection of an object in a mirror is called an *image.*

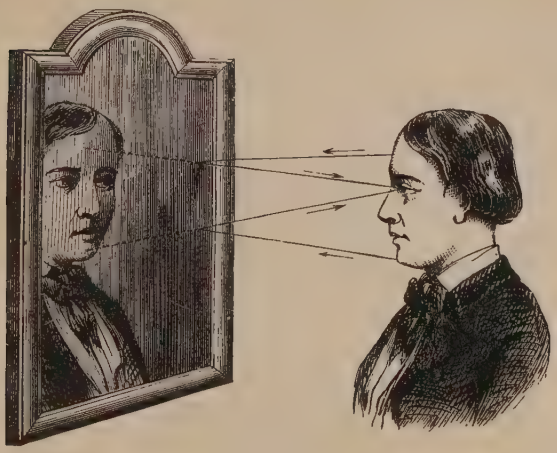


Fig. 105.

In a plane mirror the image appears *erect* and *of the size of the object.*

Illustrations. — Figure 104 shows that the rays are just as divergent after reflection as they were before reflection. The object appears to be behind the mirror, because we always see an object in the direction which the rays coming from it have *on entering the eye.*

Figure 105 shows that the visual angle is not changed by reflection from a plane mirror: hence the image appears of the same size as the object.

Objects seen reflected in a *horizontal* mirror appear *inverted*, because each part of the object

Fig. 106.

will appear just as far below the mirror as it is really above it: hence the part which is really uppermost will appear lowest in the reflection.

Fig. 107.

Illustration.— Figure 106 represents the reflection of buildings and other objects in water, and shows why they appear inverted.

136. **Reflection from Concave Mirrors.**—When light is reflected from a *concave* surface, the rays are made either to *approach each other*, or else to *separate from each other less rapidly* than they did

before reflection; that is to say, the rays are made either *convergent* or *less divergent.*

Parallel rays with a concave mirror are made to *converge*, as shown in Figure 107. The point *F*, to which they are made to converge, is called the *principal focus* of the mirror.

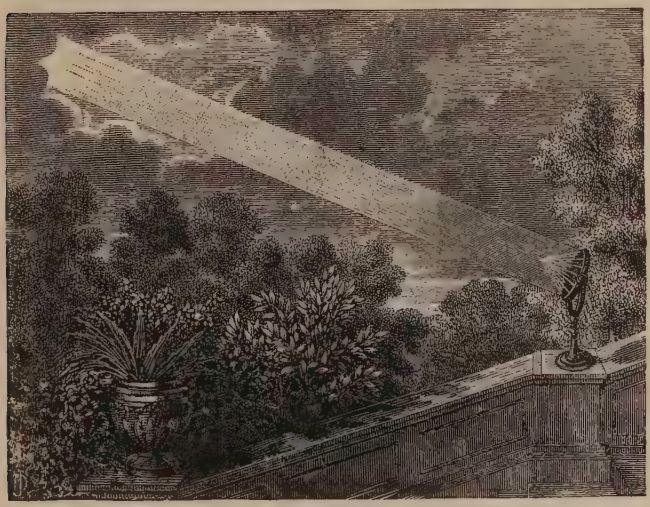


Fig. 108.

Illustration. — Were the sun's rays allowed to fall upon a concave mirror, they would be made to converge to a focus, as shown in Figure 108.

Rays *diverging* from a point *beyond the principal focus* of a concave mirror will be made to *converge* to a point also *beyond the principal focus.* The point to which they are made to converge is called a *conjugate* focus.

Illustrations. — Rays diverging from the point *L* (Figure

109) will be made to converge to *l*. Rays diverging from the point *l* would be made to converge to *L*. Each of these points is the conjugate focus of the other.

Rays *diverging* from a point *within the principal focus* of a concave mirror will be made to be *less*

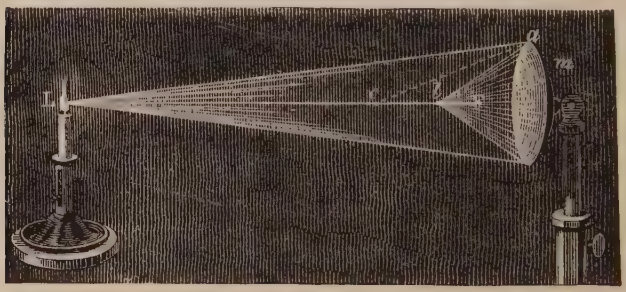


Fig. 109.

divergent after reflection, as shown in Figure 110. The point *p*, from which they appear to diverge after reflection, is called a *virtual* focus.

137. **Images formed by Concave Mirrors.** — Whenever a concave mirror makes the rays from

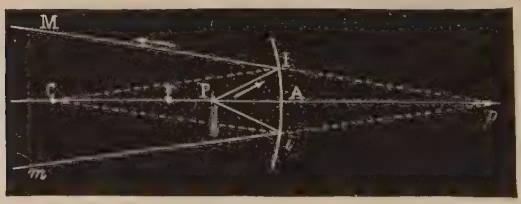


Fig. 110.

an object convergent by reflection, it forms an *inverted image* of the object. The size of this image depends upon its distance from the mirror as compared with that of the object. Whichever is nearer the mirror is the smaller.

Illustration. — The concave mirror shown in Figure 111 forms an inverted image of the distant church, which is received on a sheet of white paper held in the focus of the mirror.

Whenever a concave mirror makes the rays coming from an object *less divergent*, it enlarges the visual angle of the object, and so *magnifies* it,

Fig. 111.

as shown in Figure 112. In this case the object must be between the principal focus and the mirror; and the image, which will be *erect*, will be seen in the mirror, as in the case of the plane mirror.

138. **Reflection from Convex Mirrors.** — When light is reflected from a *convex* mirror, the rays are made *more divergent*, and the visual angle is

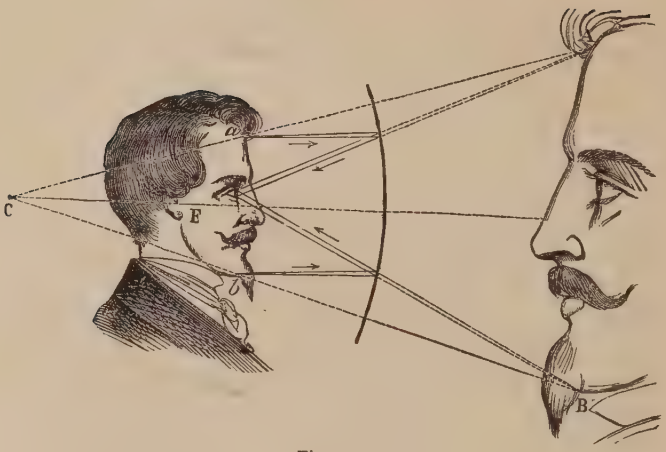


Fig. 112.

made *smaller*. Such mirrors form *erect* images

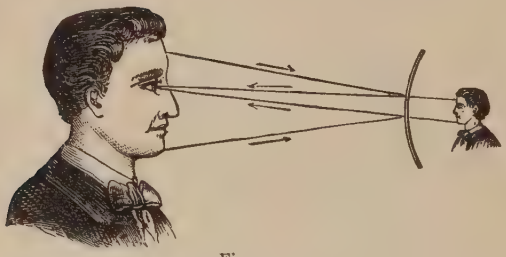


Fig. 113.

which are *smaller* than the object, as shown in Figure 113.

QUESTIONS.

1. What is meant by a mirror? 2. Of what materials are mirrors usually made? 3. Name the three forms of mirrors. 4. What is meant by the visual angle? 5. Upon what does the size of the visual angle depend? 6. What is the effect produced upon the appearance of the object by a change in

the visual angle? 7. What effect has reflection from a plane mirror upon the divergency of the rays? 8. Upon the visual angle? 9. What name do we give to the reflection of an object in a mirror? 10. What kind of images do plane mirrors give? 11. Why do they appear to be behind the mirror? 12. Why do objects reflected in water appear inverted? 13. What effect has reflection from a concave mirror upon the rays? 14. What is meant by the principal focus of a concave mirror? 15. Where must a point be situated in order to have the rays diverging from it made convergent by reflection? 16. What do we mean by a conjugate focus? 17. Where must a point be situated in order that the rays diverging from it may be made less divergent by reflection? 18. What do we mean by a virtual focus? 19. When do concave mirrors form inverted images? 20. What is true of the size of these images? 21. When do concave mirrors form erect images? 22. What is true of the size of these images? 23. Why? 24. What effect has reflection from a convex mirror upon the divergency of the rays? 25. Upon the visual angle? 26. What kind of images are formed by such mirrors? 27. Why are these images smaller than the object?

CHAPTER XXI.

LENSES.

139. **Kinds of Lenses.** — A *lens* is made of glass or other transparent substance. It has at least one curved surface, and it has usually a circular outline. A front and a side view of a lens are given in Figure 114. When a lens has one or more convex surfaces, it is called a *convex* lens; and, when it has one or more concave surfaces, a *concave* lens. If a lens has both a convex and a concave surface, it is called a *convex* lens when the convex surface

curves more than the other, and a *concave* lens when the concave surface curves the more. There are three forms of lenses of each class. The six forms are shown in section in Figure 115. The first is called

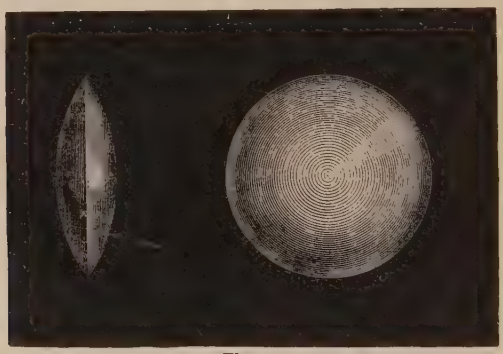


Fig. 114.

a *double-convex* lens, the second a *plano-convex*, the third a *meniscus*, the fourth a *double-concave*, the fifth a *plano-concave*, and the sixth a *convexo-concave*.

140. **Refraction by Convex Lenses.** — When light is refracted by a *convex* lens, the rays are

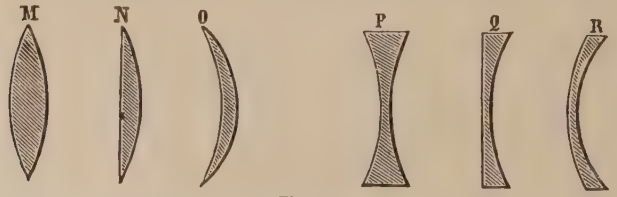


Fig. 115.

made either *to approach each other*, or else to *separate from each other less rapidly:* in other words, they become either *convergent* or else *less divergent*.

Convex lenses produce the same effects by refraction that concave mirrors do by reflection.

Parallel rays with a convex lens are made *convergent*, as shown in Figure 116. The point *F*,

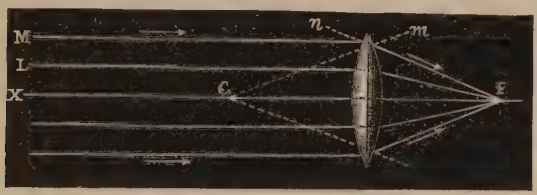


Fig. 116.

towards which they are made to converge, is called the *principal focus* of the lens.

Illustration. — Figure 117 shows the concentration of the sun's rays by means of a convex lens. The cannon is placed

Fig. 117.

in such a position that the point of concentration of the rays will fall in the right place to ignite the powder when the sun is on the meridian.

Rays *diverging* from a point *beyond the principal focus* are made to *converge* by the refraction of the lens, as shown in Figure 118. The point *l*, to which

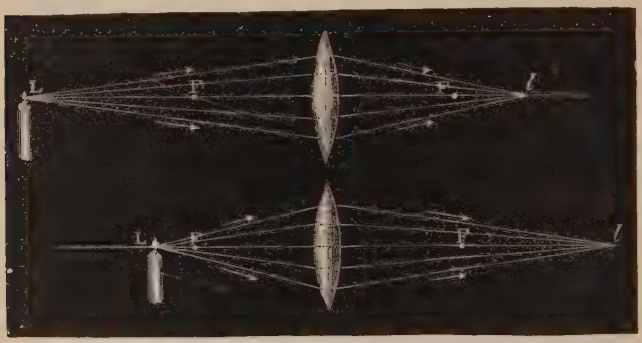


Fig. 118.

they are made to converge, is called the *conjugate* focus. The nearer the point of divergence to the principal focus, the more remote its conjugate focus.

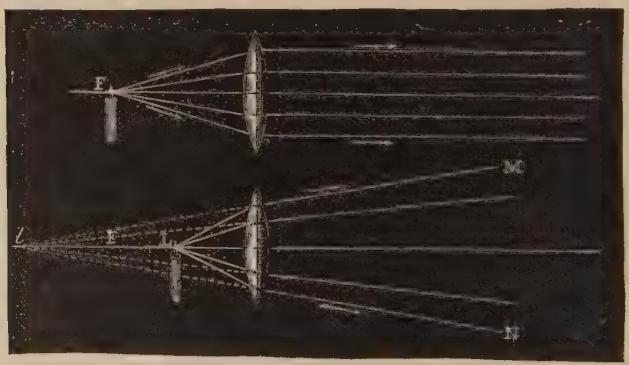


Fig. 119.

Rays *diverging* from a point *at the principal focus* become *parallel* after refraction, as shown in Figure 119.

Rays *diverging* from a point *within the principal*

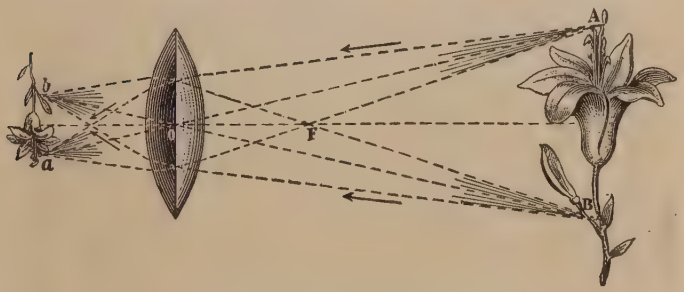


Fig. 120.

focus become *less divergent* after refraction by the lens, and have a virtual focus at *l* (Figure 119).

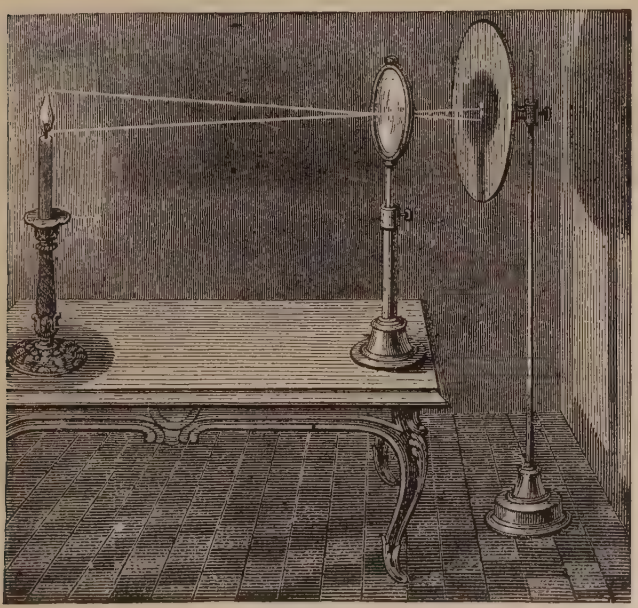


Fig. 121.

141. **Images formed by Convex Lenses.** — Con-

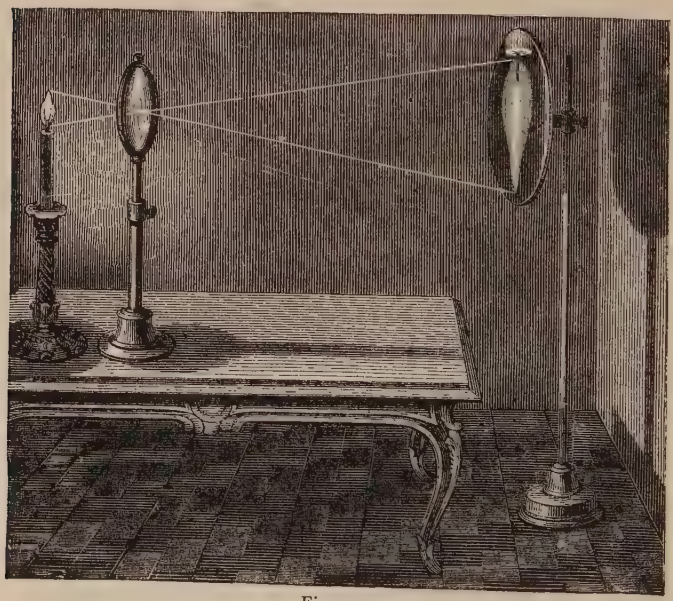


Fig. 122.

vex lenses form *inverted images* of objects which

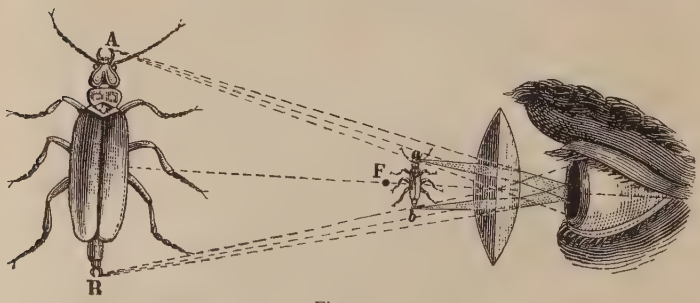


Fig. 123.

are *beyond their principal foci*, as shown in Figure 120.

When the object is *farther from the lens* than the image is, the image is *smaller* than the object, as shown in Figure 121.

When the object is *nearer the lens* than the

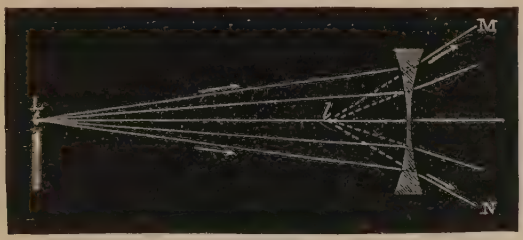


Fig. 124.

image is, the image is *larger* than the object, as shown in Figure 122.

When the object is placed *within the principal focus* of a convex lens, an *enlarged* image of it is obtained, as shown in Figure 123. *a b* is the object,

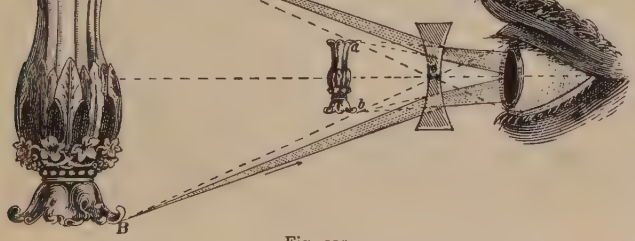


Fig. 125.

and *A B* the image. It is enlarged, because the visual angle is increased by the refraction.

142. **Refraction by Concave Lenses.** — When light passes through a *concave* lens, the rays are

made *more divergent* by refraction, as shown in Figure 124.

A concave lens forms an *erect* image, which is *smaller* than the object, as shown in Figure 125.

Fig. 126.

A B is the object, and *a b* its image. The image is smaller than the object, because the refraction makes the visual angle smaller.

143. **The Camera Obscura.** — If light is admitted

through an opening into a darkened room, and then reflected through a convex lens, as shown in Figure 126, a picture of the outside view will be

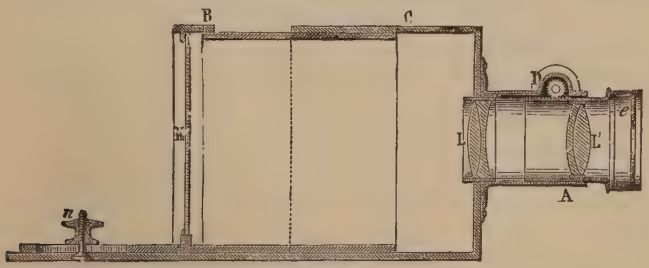


Fig. 127.

formed upon a screen placed in a proper position to receive it. Such a darkened room is called a *camera obscura.*

Illustrations. — Figure 127 shows in section the camera used by photographers. BC is the dark chamber, LL' are

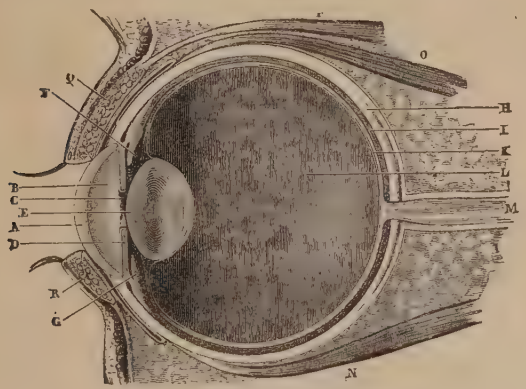


Fig. 128.

the lenses through which the light passes, and E is the screen for receiving the picture. When a person sits in front of

these lenses, a small inverted picture of him is formed on the screen.

The *eye* is a small camera obscura. The parts of the eye are shown in Figure 128. *A* is the *cornea* (the transparent convex covering of the front of the eye), and *E* the *crystalline lens*, which is a double-convex lens. These correspond to the lenses in the photographer's camera. *D* is the *iris*, a sort of

Fig. 129.

curtain before the crystalline lens, giving the color to the eye; *C* is the *pupil*, or opening through the iris by which the light is admitted; *K* is the *retina*, which contains the fibres of the *optic nerve* on the back of the eye. This answers to the screen in the camera. Figure 129 illustrates the formation of the image on the retina by the action of the lenses of the eye.

QUESTIONS.

1. What is a lens? 2. What are the two classes of lenses? 3. Name the three lenses of each class, and tell what surfaces each has. 4. What effects do convex lenses produce upon a ray of light by refraction? 5. What is meant by the principal focus of a convex lens? 6. By a conjugate focus? 7. Upon what does the distance of a conjugate focus from a lens depend? 8. What rays have a virtual focus with a convex lens? 9. When do convex lenses form inverted images of objects? 10. When is the image larger than the object? 11. When is it smaller than the object? 12. When does a convex lens form an erect image of an object? 13. Why? 14. What is

the size of the image compared with that of the object? 15. Why? 16. What effects do concave lenses produce on rays of light by refraction? 17. What images of objects do concave lenses form? 18. What is the size of these images compared with that of the objects? 19. Why? 20. Describe a camera obscura. 21. Describe the photographer's camera. 22. Describe the eye. 23. What kind of an optical instrument is the eye.

VII.

ELECTRICITY.

CHAPTER XXII.

FRICTIONAL ELECTRICITY.

144. **Electrification by Friction.** — Many substances when rubbed together become *electrified*, or charged with *electricity;* that is, they acquire the power of attracting and repelling light bodies.

Fig. 130.

Illustration. — Rub a dry glass rod with silk, and hold it near bits of paper or pieces of pith, and it will attract these bodies; and, if it is strongly excited, it will afterwards repel them (Figure 130). A piece of sealing-wax or of vulcanite, when rubbed with flannel or fur, also acquires the same property of attracting light bodies.

145. **Conductors and Insulators.** — Metals and certain other substances allow electricity to pass

off readily through them. Such substances are called *conductors.* Other substances, such as glass, silk, sealing-wax, and dry air, will not allow electricity to pass through them. Such substances are called *insulators.* A conductor when entirely surrounded by insulators is said to be *insulated.* A brass cylinder supported on a glass rod, or a pith ball hung on a silk thread, is insulated.

Illustrations. — A brass rod held in the hand, and rubbed with a cat-skin, does not become electrified; the electricity passing off through the hand as rapidly as it is developed. A brass cylinder when supported on a glass rod becomes powerfully electrified when stroked with the cat-skin; the glass rod preventing the escape of the electricity.

146. **Two Kinds of Electricity.** — The electricity which is excited on *glass* when rubbed with *silk* is the opposite in kind to that excited on *vulcanite* when rubbed with *fur.* The former kind of electricity is called *positive* electricity; and the latter, *negative* electricity. *Bodies charged with unlike electricities attract, and those charged with like electricities repel, each other.*

Illustration. — Excite a glass rod by rubbing it with silk, and present it to a pith ball hung on a silk thread (Figure 131). The ball will at first be attracted to the rod, and then repelled from it. After it has once been repelled, it can no longer be made to touch the glass rod. Excite now a vulcanite tube by rubbing it with fur, and present it to a second pith ball hung on a silk thread. This pith ball will also be attracted, and then repelled. Present the excited vulcanite to the ball which is repelled by the glass, and it will be attracted. Present the excited glass to the ball that is repelled by the vulcanite, and it will also be attracted. Bring the two pith

balls slowly together, and they will be found to attract each other. Charge the two pith balls by allowing both to come in contact with either the vulcanite or the glass, and they will repel each other.

147. **Electrical Machines.** — A machine for developing electricity by friction consists of a glass plate arranged so as to turn between two rubbers. One form of the machine is shown in Figure 132.

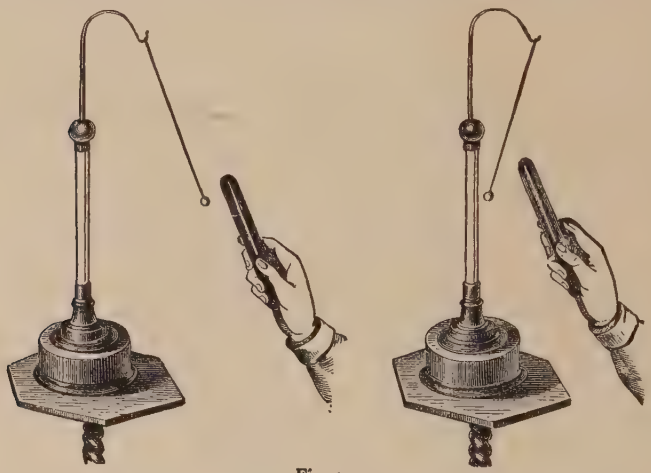


Fig. 131.

The brass cylinders, which are supported upon glass rods, form what is called the *prime conductor.* In small machines a single cylinder is used. *Negative* electricity is developed on the *rubbers*, and conveyed to *the earth. Positive* electricity is developed on the *glass*, and passes to the *prime conductor.*

148. **Electrical Induction.** — If an insulated conductor is placed near the prime conductor of an electrical machine in action (Figure 133), the prime

conductor will act upon it by *induction* through the air which separates the two. No electricity passes from the prime conductor to the other; but *negative* electricity is developed on the *near* end of the insulated conductor, and *positive* electricity on its *farther* end. A charged body always acts by induc-

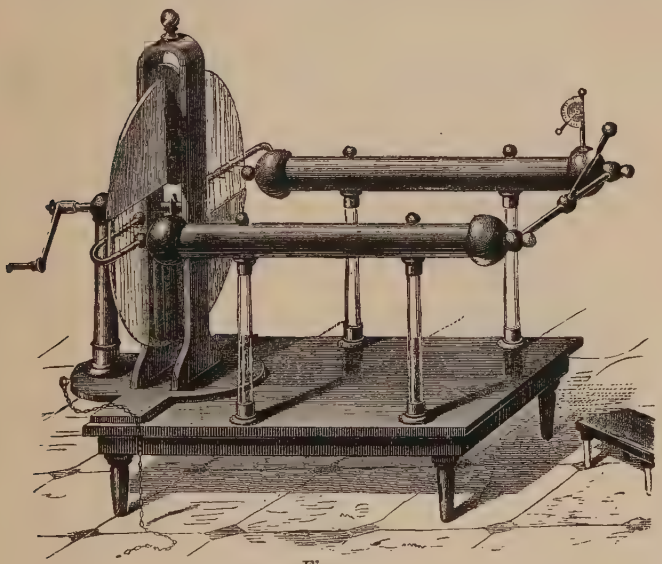


Fig. 132.

tion on all surrounding conductors; driving its own kind of electricity to the farther end of these conductors, and drawing the opposite electricity to the near end.

If the conductor is removed from the machine without touching the cylinder, it loses all trace of electricity. If we touch the cylinder with the finger before we remove the conductor, we shall

find, on removing the conductor, that it is charged with negative electricity. The positive electricity was driven off through the hand into the earth.

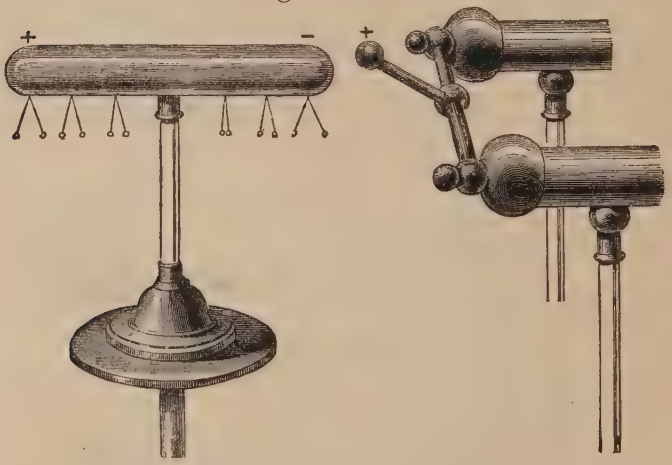


Fig. 133.

The finger must be removed from the conductor before the conductor is taken from the influence of the machine.

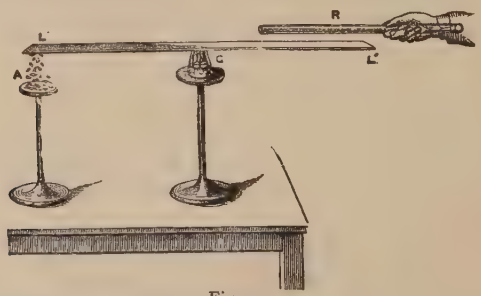


Fig. 134.

Illustration. — Balance an ordinary lath on a piece of glass or vulcanite, as shown in Figure 134, and place some light

bodies on a stand under one end of it, and then bring an excited vulcanite tube near the other end: the light bodies will immediately be attracted.

149. **The Electrophorus.** — The *electrophorus* consists of a cake of wax provided with a metallic lid which has an insulating handle. The wax is first excited by stroking it with cat-skin. The lid is then placed upon it, and touched with the finger as shown in Figure 135. On removing the finger, and raising the disk, a spark may be drawn from it, as shown in Figure 136. This operation may be repeated any number of times without re-exciting the wax. The disk becomes charged by induction. No electricity passes from the wax to the lid.

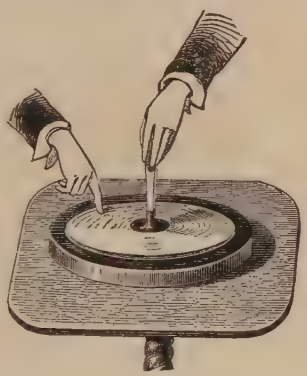
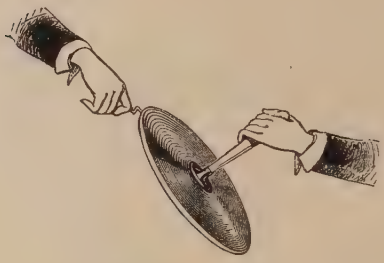


Fig. 135.

150. **The Holtz Electrical Machine.** — In the *Holtz machine* electricity is developed by *induction.* This machine is shown in Figure 137. It consists essentially of two plates of glass near together, one of which is stationary, and the other capable of rotating. There are two pieces of paper pasted upon the stationary plate, at opposite parts. One of these pieces of paper is excited by friction, and acts like the excited wax of the electrophorus. As the rotating plate turns in front of this paper, electricity is developed on it by induction, and passes off to the two rods

at the front. When this machine is in action, a perfect torrent of sparks will pass between these two rods when separated from each other.



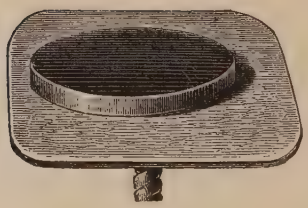


Fig. 136.

151. **Spark Discharge.** — The passage of electricity from one body to another is called *electric discharge.* The most common form of electric discharge is the *spark discharge.* This is the usual form of discharge in the air of ordinary density. The *light* of the spark is due to the fact that the air is heated white-hot by the passage of the electricity through it. The *noise* of the spark is due to the sudden expansion and contraction of the air, as it is suddenly heated by the passage of the electricity, and as it quickly cools after the passage.

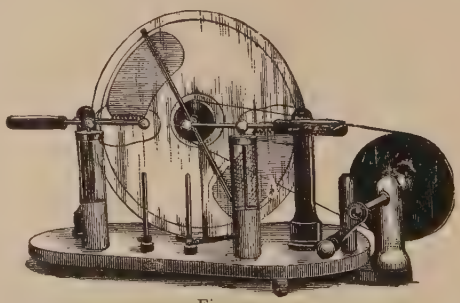


Fig. 137.

Fig. 138.

Illustrations. — When the knuckle or other conductor is

Fig. 139.

presented to a charged body, a spark passes between the two. When the rods of a powerful Holtz machine are separated

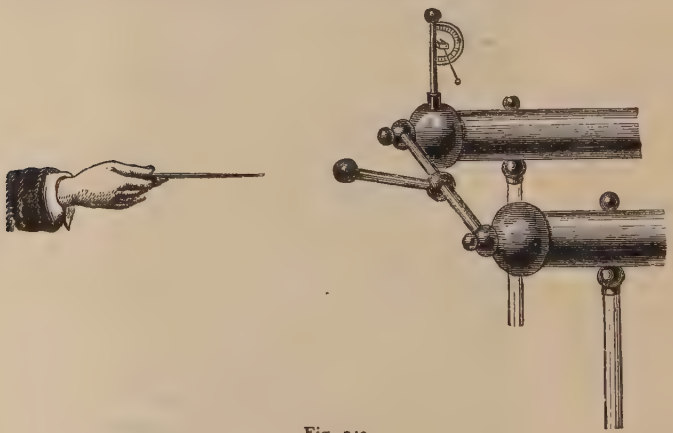


Fig. 140.

twelve or fifteen inches, brilliant zigzag sparks pass between

them, as shown in Figure 138. Lightning is simply a spark

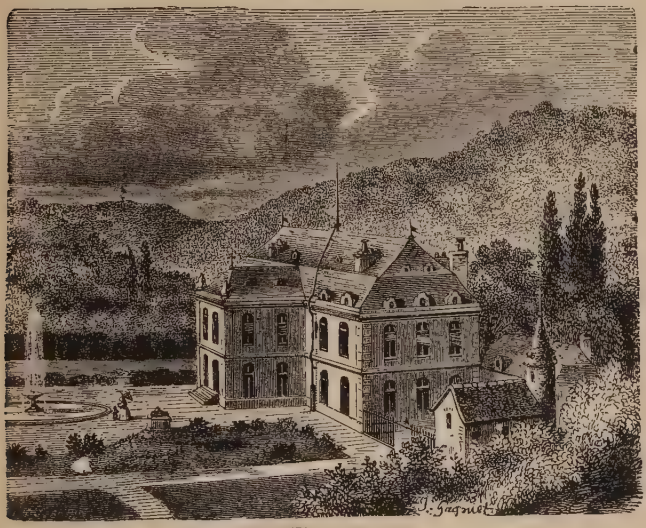


Fig. 141.

discharge, on an enormous scale, between two clouds, or be-

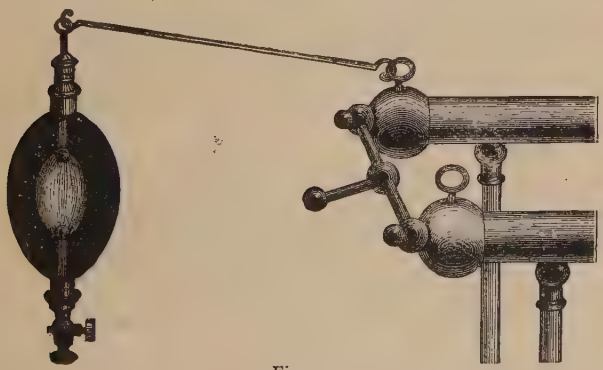


Fig. 142.

tween a cloud and the earth (Figure 139). Thunder is merely the intensified sound of the spark.

152. **Silent Discharge.** — It is found impossible to charge to any extent the prime conductor of an electrical machine or other body which has a metallic point attached to it, or held near it, as

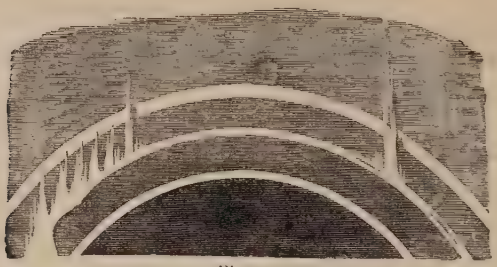


Fig. 140.

shown in Figure 140. The point causes a *silent* discharge.

Illustration. — A building may be protected from injury by lightning by placing upon it a metallic rod running well into the ground at the bottom, and well pointed at the top, as

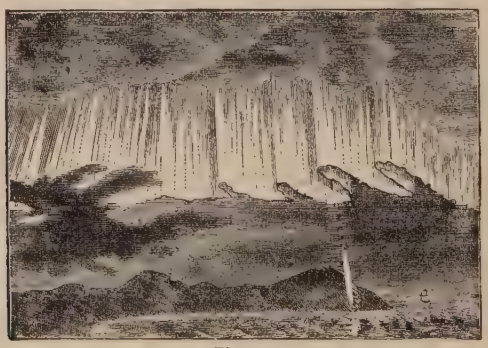


Fig. 144.

shown in Figure 141. The point serves to carry off the electricity silently from the cloud. The rod also serves as a path for the electricity to escape to the earth in case a violent discharge takes place.

153. **Auroral Discharge.** — When the discharge takes place through a vessel containing *highly rarefied air*, we get a soft diffused band of light, as shown in Figure 142, instead of the sharp line of the spark discharge. This discharge is also silent. It is called the *auroral* discharge.

Illustrations. — The Northern Lights are caused by an auroral discharge high up in the atmosphere. This light usually appears in the form of one or more arches, as shown in Figure 143, which sometimes resemble an immense curtain hanging in folds, as shown in Figure 144. These arches are usually surmounted by a number of streamers.

QUESTIONS.

1. How may bodies be electrified? 2. Give some examples. 3. What do we mean by conductors? 4. By insulators? 5. By an insulated conductor? 6. Name some conductors. 7. Some insulators. 8. How many kinds of electricity are there? 9. Name them. 10. How may we develop each? 11. When do electrified bodies attract, and when repel, each other? 12. Give illustrations. 13. Describe the ordinary electrical machine. 14. What is meant by electrical induction? 15. What takes place in induction? 16. What is the state of a conductor after it has been removed from a charged body without having been touched by the finger? 17. When it has been removed after having been touched with the finger? 18. Describe the electrophorus. 19. Describe its use. 20. By what means is the lid charged? 21. What electrical machine develops electricity by induction? 22. Describe this machine. 23. What is meant by electric discharge? 24. What is the most common form of electric discharge? 25. To what is the light of the spark due? 26. The sound of the spark? 27. Give illustrations of the spark discharge. 28. What is lightning? 29. What is the cause of thunder? 30. What is the effect of points on charged bodies? 31. For what purpose is

a lightning-rod used? 32. Describe the rod, and tell in what two ways it acts. 33. What is meant by the auroral discharge? 34. What are the Northern Lights? 35. Of what two portions are the Northern Lights usually composed?

CHAPTER XXIII.

VOLTAIC ELECTRICITY.

154. **Voltaic Cell.** — The simplest form of a *voltaic cell* consists of a plate of zinc and a plate of copper immersed in dilute sulphuric acid, as shown in Figure 145. The ends of the plates which are above the liquid are connected by means of a copper wire. When the plates are thus connected, there is a steady *flow of electricity* through the wire from the copper to the zinc, and through the liquid from the zinc to the copper. This flow of electricity is called the *electric current.* The electricity developed in this way by the action of the liquid upon the plate of a cell is called *voltaic* electricity, from Volta, an Italian philosopher, who was one of the first to study it.

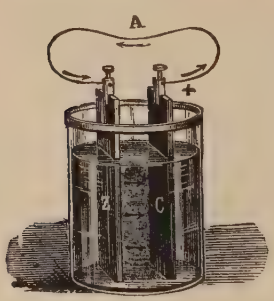


Fig. 145.

There is a great variety of voltaic cells. A cell in common use, and called *Bunsen's cell,* is shown in Figure 146. It consists of a vessel *A*, which is filled with dilute sulphuric acid. In this is placed

a cylinder of zinc *B*, and within this cylinder of zinc is placed the porous cup *C*, which contains

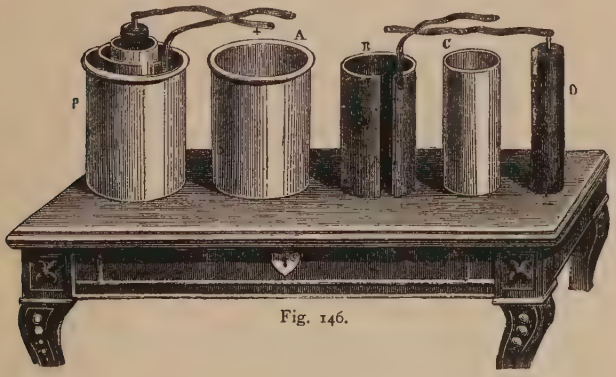


Fig. 146.

nitric acid; and finally the rod of carbon *D* is placed within the porous cup. *Daniell's cell* is shown in Figure 147. The outer vessel *A* contains a cylinder of copper and a solution of blue vitriol. The inner cup *P* contains the zinc plate and dilute sulphuric acid.

Fig. 147.

A number of voltaic cells connected together constitute what is called a *voltaic battery*. The free zinc plate at one end of the battery is

its *negative pole*, and the free carbon or copper at the other end is the *positive pole*. The wire which connects the two poles is called the *circuit*.

155. **The Voltaic Arc.** — When a powerful current of electricity is sent through two carbon points *a* and *b* (Figure 148), which have first been brought into contact, and then separated a little, a very bril-

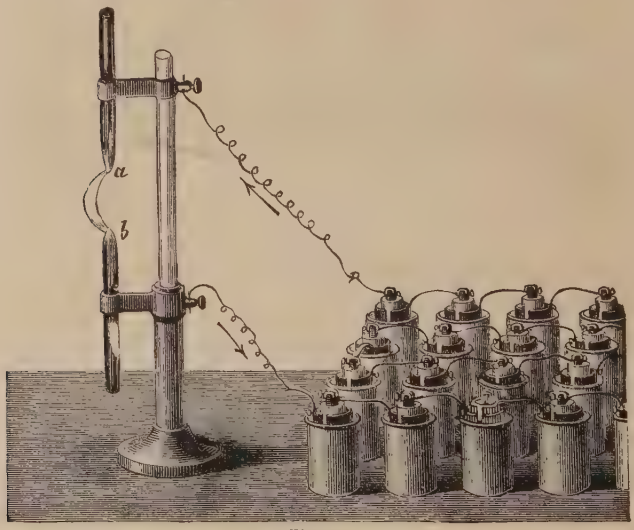


Fig. 148.

liant luminous arc is obtained. This arc is called the *voltaic arc*. The light and heat of this arc are the most intense that can be obtained by artificial means. The voltaic arc is now extensively used for outdoor illumination, as shown in Figure 149. The electric currents employed for this purpose are not usually developed by a battery, but by another method, which will be described hereafter.

156. **Illumination by Incandescence.** — When a powerful current of electricity is sent through a fine wire or rod of any substance, the wire or rod is heated white-hot, and glows with a brilliant light.

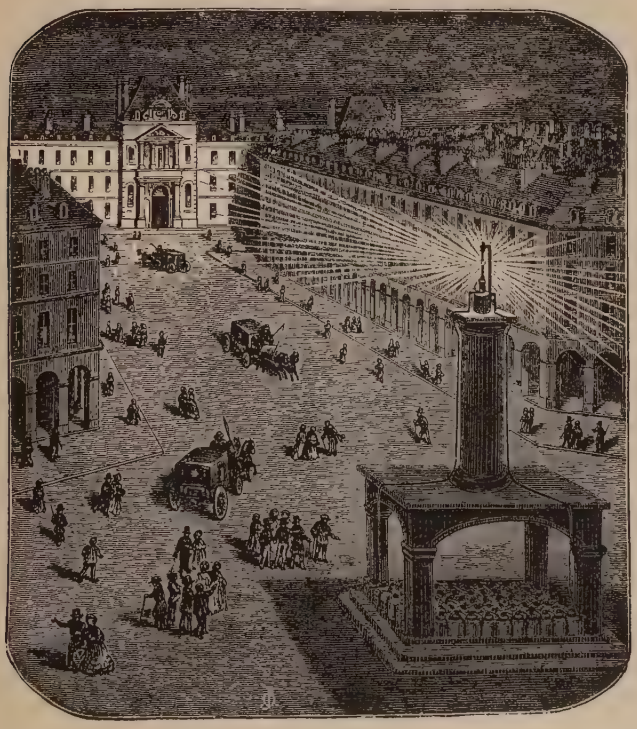


Fig. 149.

Such wires or rods are used for illumination by *incandescence*. The chief difficulty in this method is, that a wire made of any known substance is very liable to melt off when a powerful current is sent through it; and a fine rod of any substance like

carbon, which will not melt, is liable to be burned up in the intense heat. The method of incandescence is preferable for indoor illumination.

Figure 150 shows one form of lamp employed for this kind of illumination. The upper portion of the lamp is a glass globe from which the air has been exhausted, and which is sealed air-tight. In the centre of this globe is a carbon filament, bent in the form of a ring. The ends of this filament are held in little clamps connected with platinum wires, which pass through the glass of the smaller globe under the ring, and thence out through the bottom of the lamp, where they are connected with the wires of the circuit.

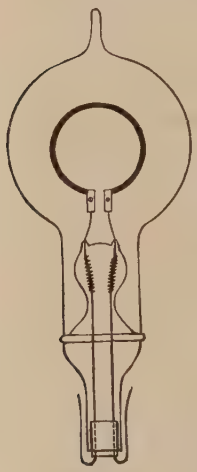


Fig. 150.

157. **Electrolysis.** — When a current of electricity is sent through water or other compound liquid, as shown in Figure 151, the liquid is *decomposed*. The current is introduced into the liquid by means of metallic strips seen at the bottom of the vessel. Water is decomposed into hydrogen and oxygen; and these gases may be collected in tubes, as shown in the figure. The decomposition of a substance by means of the electric current is called *electrolysis*. The two metallic strips by which the current is introduced into the liquid are called the *electrodes:* the one connected with the positive pole of the battery, the *anode;* and the one connected with

the negative pole, the *cathode.* When the liquid contains a compound of a metal, the metal is always set free at the cathode, and is deposited upon it.

This *deposition of metals by means of the electric current* is called *electro-metallurgy*, and is of great practical importance. The two chief processes of electro-metallurgy are *electrotyping* and *electroplating.* The former is *copying* by means of electricity, and the latter is *coating the baser metals with the more noble* by means of electricity.

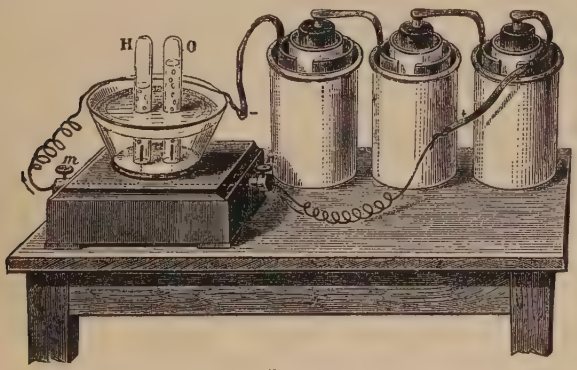


Fig. 151.

158. **Electrotyping.** — Any thing may be electrotyped of which a mould may be taken in wax. The chief use of electrotyping is in *copying the face of printers' type and wood-engravings,* after they have been arranged for the pages of a book.

A mould is first taken in wax of the article to be copied, and the wax is coated with a thin film of some conducting substance, such as graphite powder. The mould is then hung up in a trough filled with a solution of sulphate of copper (blue

vitriol), called the *bath*. The mould is connected with the negative pole of the battery (Figure 152), so as to make it a cathode. A plate of copper is hung in the bath opposite the mould, and connected with the positive pole of the battery, so as to make it an anode. On the passage of the current through the bath, copper is deposited from the solution upon the mould in a uniform sheet. The moulds are

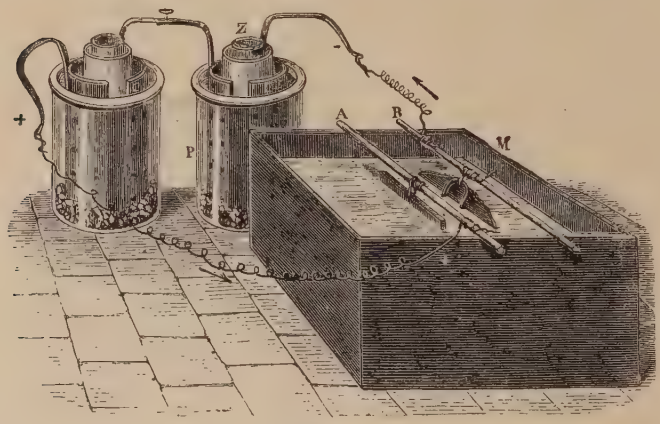


Fig. 152.

usually hung in the bath at night, and in the morning they are removed, and the wax melted off. The copper casts are made sufficiently firm for use in printing by *backing* them with type-metal.

159. **Electroplating.** — Table-ware, such as knives, forks, tea-sets, etc., is *plated with silver by electrolysis*. The article to be plated is very carefully cleaned, and hung in a bath containing a solution of cyanide of silver. It is then connected with the negative pole of a battery (Figure 153), while a piece

of silver opposite it is connected with the positive pole. On the passage of the current, silver is de-

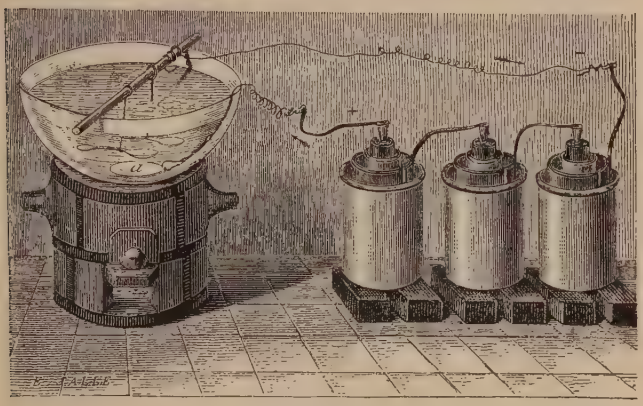


Fig. 153.

posited from the solution upon the article forming the cathode, to which it firmly adheres.

QUESTIONS.

1. Describe a simple voltaic cell. 2. Bunsen's cell. 3. Daniell's cell. 4. What is a voltaic battery? 5. What are its poles? 6. What is the circuit? 7. What is the voltaic arc? and how is it obtained? 8. What is true of its light and heat? 9. What is now a common use of this arc? 10. What is illumination by incandescence? 11. What are the chief difficulties in this method? 12. Describe one form of lamp used. 13. What is electrolysis? 14. Give an illustration. 15. What is meant by the electrodes? 16. By the anode? 17. By the cathode? 18. What takes place when the liquid contains a metallic compound in solution? 19. What is electro-metallurgy? 20. What are its two chief processes? 21. What is electrotyping? 22. What is its chief use? 23. Describe the process. 24. What is electroplating? 25. Describe the process.

VIII.

ELECTRO-MAGNETISM.

CHAPTER XXIV.

ELECTRO-MAGNETS.

160. **Permanent Steel Magnets.** — Magnets are recognized by their peculiar property of *attracting iron.* Ordinary magnets are bars of steel, either straight, or bent into the form of a horseshoe. A magnet poised so as to turn freely, as shown in Figure 154, always takes a north and south direction. Such a magnet is called a *magnetic needle.* The end of the magnet which points towards the north is called its *north pole;* and the end which points towards the south, the *south pole.* The power of a mag-

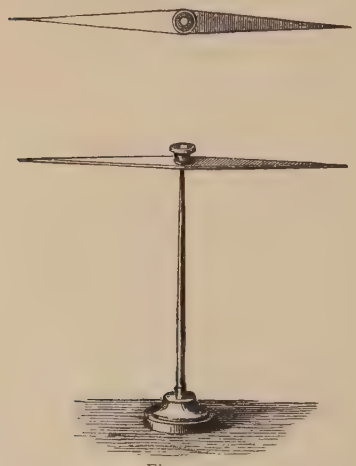


Fig. 154.

net resides chiefly in its poles. *Unlike poles of magnets attract, and like poles repel, each other.*

Fig. 155.

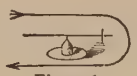


Fig. 156.

Illustrations. — Place a bar magnet in iron filings: on removing the bar, the filings will be seen to cling chiefly to the ends of the magnet. Present the north pole of a bar magnet to the north pole of a magnetic needle. The needle will be repelled. Present the south pole of the bar to the north pole of the needle. The needle will be attracted.

161. **Magnetic Induction.** — When a piece of iron is brought near a magnet, or in contact with it, the iron becomes magnetic by *induction.* As soon as the iron is removed from the influence of the magnet, it loses its magnetism. The iron and the magnet act upon each other in such a way that any movement of the iron near the magnet changes the strength of the magnet. When a piece of steel is brought in contact with a magnet, it also becomes magnetic by induction; but, when it is removed from the magnet, it retains its magnetism.

Fig. 157.

Illustrations. — Place a small nail upon the pole of a large bar magnet. The nail will become magnetic, and will be able to take up a second nail, which, in turn, will become magnetic, and take up a third; and so on. Rub a knife-blade upon a magnet, and it will acquire the power of taking up a tack, and will retain this power for a long time.

162. **Galvanometers.** — When a wire through which an electric current is passing is held over a magnetic needle, as shown in Figure 155, the needle is turned aside, or *deflected.* If the same wire is held under the needle, it is deflected in the opposite direction. The needle seeks to place itself *at right angles to the wire.* When the wire passes around the needle, as shown in Figure 156, its action on the needle is more powerful; and it may be still further increased by winding the wire several times around the needle. A needle surrounded by a coil of wire is called a *galvanometer.* It serves to show the *presence*, the *strength*, and the *direction* of the current in the wire to which it is attached. It shows the first by the *deflection* of the needle, the second by the *amount* of its deflection, and the third by the *direction* in which it is deflected.

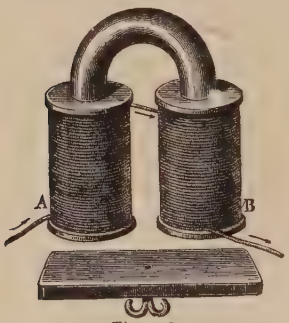


Fig. 158.

163. **Electro-Magnets.** — When a current of electricity is sent through a wire which is wound around a rod of soft iron, as shown in Figure 157, *the iron becomes a magnet.* The iron remains a magnet as long as the current is passing, but loses its magnetism the instant the current is stopped. A piece of iron placed thus within a coil of wire is called an *electro-magnet.* These magnets are far more powerful than ordinary steel magnets; and they can

be made active or inactive by simply starting and stopping the current in the wire. Any change in the current in the coils, whether in strength or direction, produces a change of magnetism in the iron. These magnets are sometimes straight, but usually bent into the form of a letter *U*, as shown in Figure 158. When bent in this way, the wire is not coiled around the whole length of the iron bar, but only around its ends, or *poles*. The bent portion of

Fig. 159.

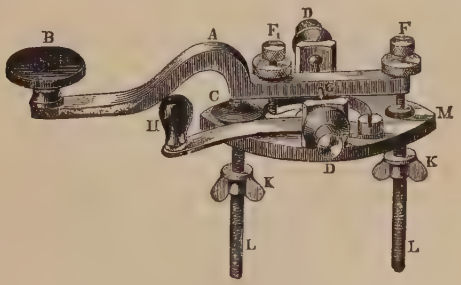


Fig. 160.

the bar is often replaced by a straight bar of iron, which connects the rods within the two coils, as shown in Figure 159.

164. **The Morse Key.** — The *Morse key* is an instrument for opening and closing the circuit, so as to stop and start the current from the battery. The complete key is shown in Figure 160, and the essential parts of it are shown in outline in Figure 161. *K* is a metallic bar called the *lever; a* is the axis on which it turns; *b* is a

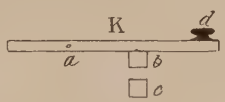


Fig. 161.

platinum point connected with the lever; *c* is a stationary platinum point directly under *b*, called the *anvil;* and *d* is a vulcanite button by which the lever is pressed down. There is a spring under the lever of the key which keeps it up so as to separate the platinum points when the lever is not pressed down.

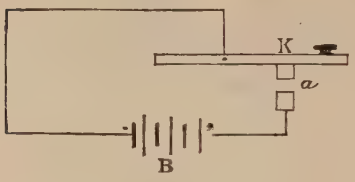


Fig. 162.

In Figure 162 the key is shown in the circuit of a battery. One pole of the battery is connected with the anvil by a wire, and the other with the lever at the axis.

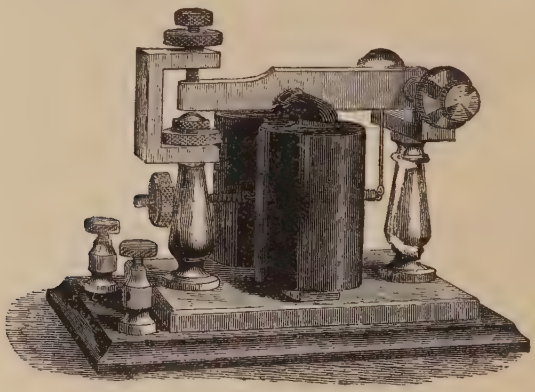


Fig. 163.

When the lever is up, the circuit is opened at *a* by the separation of the platinum points, and the current is stopped. When the lever is pressed down, the circuit is closed by the contact of the platinum points at *a*, and the current starts.

165. **The Telegraphic Sounder.** — The *sounder* is shown in Figure 163, and its essential parts in outline in Figure 164. *A* is an electro-magnet; *L* is a lever; *b* is the axis on which the lever turns; *c* is a spring which pulls the lever up; *e* is a piece of soft iron, fastened across the lever just over the electro-magnet; and *d* is a piece of metal against which the lever strikes when it is drawn down.

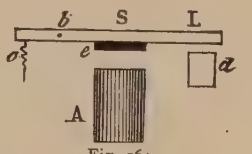


Fig. 164.

Figure 165 shows the *sounder and key in circuit.* One pole of the battery is connected by a wire with the circuit of the key; the other pole is connected with one end of the wire of the electro-magnet of the sounder; and the other end of this wire magnet is connected with the lever of the key at the axis.

When the lever of the key is up, the circuit is broken at *a*, the current is stopped, the electro-magnet of the sounder is inactive, and the lever of the sounder is thrown up by the spring. If the lever of the key is pushed down, contact is made at *a*, which closes the circuit; the current starts, the electro-magnet of the sounder becomes active, and the lever of the sounder is drawn down by the pull of the magnet upon the iron above it. As the lever is drawn down, it *clicks* from striking the metallic stop at the end.

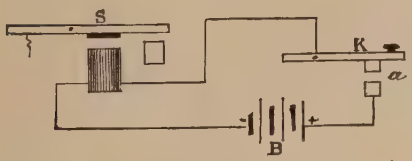


Fig. 165.

The clicking of the sounder is controlled by the key, even when these are miles apart; for the sounder clicks every time the lever of the key is depressed. Letters and words are indicated *by combinations of long and short intervals between the*

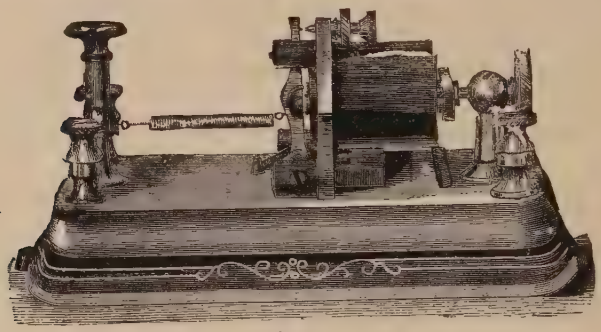


Fig. 166.

clicks. The operator listens to the sounder just as we listen to a person who is talking to us, and soon becomes able to follow it as readily.

166. **The Telegraphic Relay.** — On long lines, in which there are a number of stations, the current from the main battery is *not strong enough to work the sounders with sufficient force.* This necessitates the use of an instrument called the *relay* (Figure 166), by means of which a local battery is made to work the sounder. Its essential parts are shown in outline in Figure 167. *A* is an electro-magnet; *l* is the lever, which turns upon an axis at *b*; *c* is a piece of soft iron fastened across the lever in front of the electro-magnet; *f* is a spring for pull-

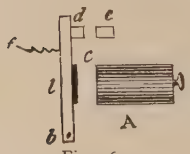


Fig. 167.

ing the lever back; *d* and *e* are two platinum points, the former fastened to the lever, and the latter stationary.

Figure 168 shows the way in which the key, relay, and sounder are connected. The full line represents the circuit of the main battery *M;* and the dotted line, of the local battery *L*. One pole of the main battery is connected with the anvil of the key, and the other with one end of the wire of the electro-magnet of the relay. The other end of the wire of this magnet is connected with the lever of the key at the axis. One pole of the local battery is connected to the lever of the relay, and the other pole to the electro-magnet of the sounder, and then to the stationary platinum point of the relay. When the lever of the key is up, the main circuit is opened at *a;* the current is stopped, the electro-magnet of the relay is inactive, the lever of the relay is drawn back by the spring, the local circuit is opened at *b* by the separation of the platinum points, the electro-magnet of the sounder is inactive, and the bar of the sounder is thrown up by the spring. When the lever of the key is pushed down, contact is made at *a*, the main circuit is closed, the electro-magnet of the relay becomes active, the lever of the relay is drawn forward, contact is made at *b*, the local circuit is closed, the electro-magnet of the sounder becomes active, and the lever of the sounder is drawn down. Thus *the levers of the relay and sounder vibrate in unison, but each is worked by a different battery.* The vibration of the lever of the relay is controlled

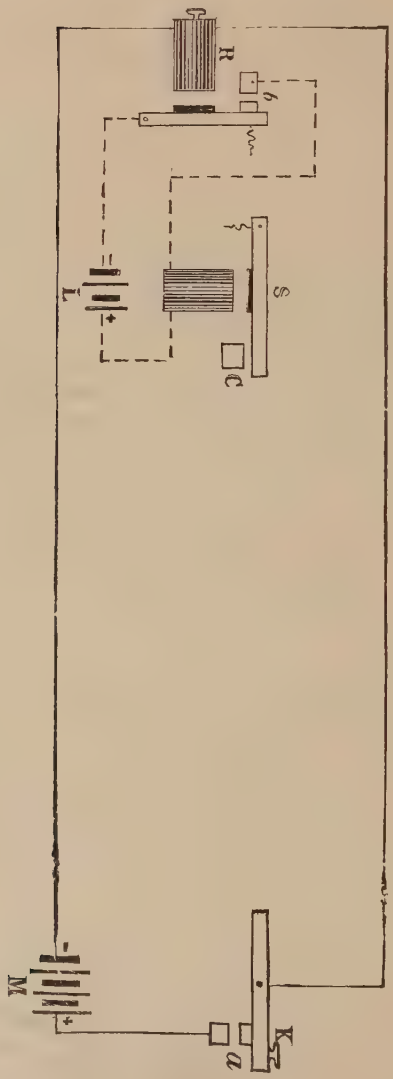


Fig. 168.

by the key, and controls the vibration of the lever of the sounder by opening and closing the local circuit.

QUESTIONS.

1. What is the distinguishing property of a magnet? 2. What are the two forms of magnets? 3. What is a magnetic needle? 4. What are the north and south poles of a magnet? 5. How do like and unlike poles of magnets act upon each other? 6. Give illustrations. 7. What is meant by magnetic induction? 8. What is the difference in the effect upon iron and steel when brought under the influence of a magnet? 9. What effect has every movement of a piece of iron near a magnet upon its magnetism? 10. What is the effect of a current of electricity upon a magnetic needle? 11. How may this effect be increased? 12. What is a galvanometer? 13. What are its uses? 14. What is an electro-magnet? 15. How does it compare with a steel magnet in strength? 16. How may it be rendered active and inactive? 17. For what is the Morse key used? 18. Describe the instrument. 19. Describe its connection with the circuit of a battery. 20. Explain how it opens and closes the circuit. 21. Describe the telegraphic sounder. 22. Describe how it and the key may be connected in the same circuit. 23. Explain how the key may make the sounder click. 24. What may be indicated by the clicks of the sounder? 25. In what way? 26. Why is it necessary to use the relay? 27. Describe this instrument. 28. Describe the way in which the relay, sounder, and key are connected. 29. Explain how the vibration of the key makes the levers of the relay and of the sounder vibrate in unison. 30. Why do the batteries make each lever vibrate? 31. Why do the levers vibrate in unison?

CHAPTER XXV.

MAGNETO-ELECTRICITY.

167. **Currents induced by Magnetism.** — When a magnet and a wire whose ends are connected are moved near each other, a current of electricity is developed by *induction* in the wire. The current continues only while the motion continues; and, if the motion is to and fro, the direction of the current is changed every time the direction of the motion is changed.

When the magnet and wire are stationary, any change in the magnetism of the magnet will induce a current in the wire, which will continue only while the change is taking place.

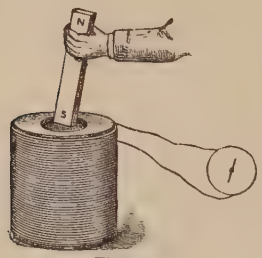


Fig. 169.

When two wires are near each other, and a current is flowing through one of them, any movement of the wires with respect to each other, or any change in the current in the one wire, will induce a current in the other wire. The current developed in any of the above ways is called an *induced* current, or a *magneto-electric* current.

Illustrations. — If a magnet *N S* (Figure 169) is moved suddenly in or out of the coil of wire, a current will be induced in the coil, which will be in one direction on inserting the pole, and in the other on withdrawing it. If the magnet is reversed, so as to use the other pole, the current will be reversed.

If the magnet is placed within the coil, and its magnetism is changed by moving a piece of iron to and fro near the pole, a current will be induced in the coil.

If a coil of wire through which a current is passing is used instead of a steel magnet (Figure 170), precisely similar results are obtained. The more suddenly the steel magnet, or the coil conveying a current, is moved in or out of the coil, the stronger the current induced.

If the small coil is left within the larger coil, *any change whatever in the current in the inner coil, whether of strength or direction, will develop a current by induction in the outer coil.*

If a bar of *soft iron* is inserted in the inner coil of Figure 170, the current induced in the outer coil, either by motion or change of current, will be *very much stronger.*

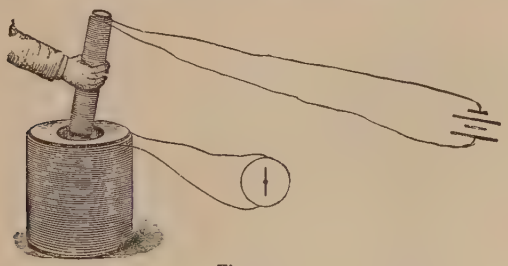


Fig. 170.

168. **The Induction Coil.** — The *induction coil* consists of two coils: an inner or *primary* coil of *coarse wire*, enclosing pieces of soft iron, usually in the form of wires; and an outer or *secondary* coil of *fine wire.* The coils are carefully insulated from each other. A current of electricity is sent through the primary coil; and *any change in the strength of this primary current develops by induction a current in the secondary coil.*

169. **The Bell Telephone.** — Figures 171 and 172 show the construction of the *Bell Telephone.*

It consists of a steel magnet *M*, around one end of which is wound a coil of fine wire *B*. The coil

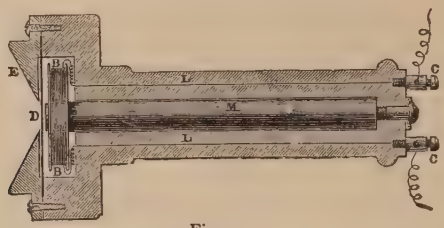


Fig. 171.

and magnet are enclosed in a wooden case, which serves as a handle. One end of this case is enlarged and hollowed out at *E*, so as to serve as a mouth-piece or an ear-piece. A diaphragm of thin iron *D* is stretched across the wide end of the case, just in front of the pole of the magnet, which it does not touch.

Fig. 172.

The transmitting and receiving instruments, which are *exactly alike* in construction, are connected by a wire. If a person speaks into the mouth-piece, the air in it is thrown into vibration, and the vibrations are communicated to the diaphragm. The vibrations of the iron plate produce slight temporary alterations in the magnetism of the steel magnet. These changes of mag-

netism in the magnet induce corresponding currents in the wire of the coil, which are transmitted over the wire connecting the two instruments: hence pulsations of electricity exactly corresponding to the vibrations of the diaphragm of the first instrument will be transmitted over the wire, and through the coil of the receiving instrument. These pulsations of the current in the coil will *induce* in the magnet of the receiving instrument *exactly the same changes of magnetism as those by which they were produced* in the sending instrument. These changes of magnetism cause the magnet to pull upon the iron plate in front of it with a varying force, and consequently to *make it vibrate exactly like the diaphragm of the transmitter.* These vibrations are communicated to the air, and then to the ear of the operator, which is placed at the mouth of the receiver. The words spoken into the transmitter are thus reproduced in the receiver.

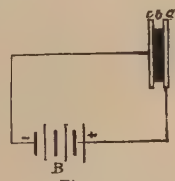


Fig. 173.

170. **The Carbon Button.** — The *carbon button* consists of a disk of carbon between two metallic plates, which are placed directly against it, as shown in Figure 173. Each metallic plate is connected with one of the poles of a battery. The slightest variation of pressure upon these plates alters the conducting capacity of the button, and changes the strength of the current flowing through it. An increase of pressure makes the current stronger, and a lessening of pressure makes it weaker. This button is exceedingly sensitive to changes of pressure.

171. **The Edison Telephone.** — There is no battery used in the Bell telephone; but in the *Edison telephone* a battery is used, and the current from the battery is thrown into pulsations by means of a carbon button.

One form of the *Edison transmitter* is shown in Figure 174. The mouth-piece is of vulcanite. Back of this is the vibrating disk, and behind this is a little round button of aluminium, which rests upon the metallic plate in front of the carbon disk. This

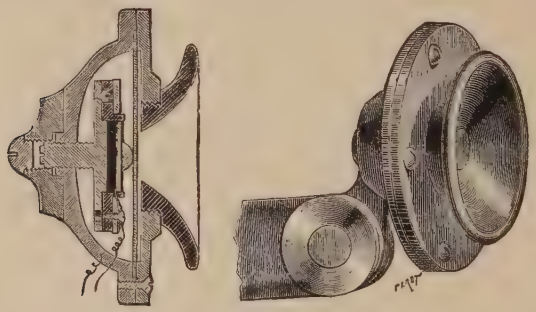


Fig. 174.

plate is of platinum. Behind the carbon disk is a second platinum plate, held in position by a screw at the back of the instrument. The battery wires are connected with the two platinum plates in such a way that the current must traverse the carbon disk.

On speaking into the mouth-piece, the disk is thrown into vibration. The vibrations are communicated to the platinum plate and the carbon disk by means of the aluminium button, thus *producing undulations in the current exactly corresponding to the vibrations of the disk.*

The *receiving instrument* of the Edison telephone is *similar to that of the Bell telephone.* Changes of magnetism are induced in it by the undulating current which traverses its coil; and these changes of magnetism *cause the disk in front of the magnet to vibrate exactly like that of the transmitter.*

172. **The Dynamo-Electric Machine.** — Powerful currents of electricity, such as those used for the electric light and for a variety of other purposes, are now developed by magneto-electric induction. The machines used are called *dynamo-electric machines*, or simply *dynamo machines.* In all of these machines the currents are developed by the

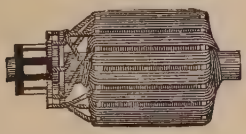


Fig. 175.

Fig. 176.

rotation of coils of wires arranged on cylinders called *armatures*, between the poles of powerful magnets. The armature of the *Edison machine* is shown in Figure 175, and a section of it is shown in Figure 176. It is a cylinder of wood, through the centre of which passes an iron rod, upon which it rotates. The wood is first wound transversely, like thread on a spool, with iron wire. It is then wound lengthwise with copper wire. The whole machine is shown in Figure 177. It consists of a large upright electro-magnet, the poles of which are the large pieces of iron seen at the bottom of the coils. These poles are hollowed out so as to receive

the armature, which they nearly enclose. The armature is rotated by means of the pulley and belt seen at the back. As the copper wires of the armature are carried around past the poles of the magnet, currents are developed by induction. The iron wire upon which the copper is wound increases the strength of the induced currents.

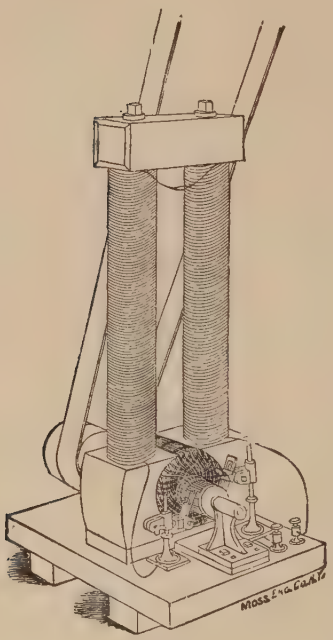


Fig. 177.

It has been found, that, if any current from an outside source is sent through the armature of any of these machines, it will make the armature revolve in the opposite direction to that in which it would have to revolve in order to develop a similar current: hence, by means of one of these machines, the electric current may be made to work machinery.

QUESTIONS.

1. Describe the first method of developing induced currents. 2. The second method. 3. The third method. 4. By what other names are these currents known? 5. Give the first illustration. 6. The second illustration. 7. The third illustra-

tion. 8. The fourth illustration. 9. What will increase the strength of the current in the last two cases? 10. Describe the induction coil. 11. Give its action. 12. Describe the Bell telephone. 13. Explain its action. 14. Describe the carbon button. 15. Explain its action. 16. Describe the Edison transmitter. 17. Explain the action of the Edison telephone. 18. In what way is the electric current developed in a dynamo-electric machine? 19. Describe the armature of the Edison machine. 20. Describe the whole machine. 21. What produces the current? 22. What strengthens the current? 23. What is the effect of sending an outside current through the armature?

APPENDIX.

THE following are given as a few random examples of familiar experiments (with apparatus found in most school collections), that may be used as additional illustrations, or for purposes of review and examination (see Preface): —

Page 31. — The fact that *all bodies fall at the same rate in a vacuum* may be mentioned, and shown with the "guinea and feather tube" (Figure 178).

Page 78. — The *upward* pressure of the air may be illustrated by the "weight-lifter" (Figure 179); and the fact that the air presses *in all directions*, by the "Magdeburg hemispheres" (Figures 180 and 181), which take their name from Otto von Guericke of Magdeburg, by whom they were invented.

Page 79. — The *rise of liquids in exhausted vessels* is strikingly illustrated by the piece of apparatus commonly known as the "fountain in vacuo" (Figure 182). The bell-jar is first exhausted, and the stop-cock at the bottom is closed. The end of the tube is then placed under water, and the stop-cock opened, when the water is driven up into the bell-jar in a beautiful fountain.

Fig. 178.

Page 107. — The fact that a *diminution of pressure lowers the boiling-point* may be called up, and Franklin's experiment (Figure 183) per-

formed to illustrate it. The water in the flask is first boiled,

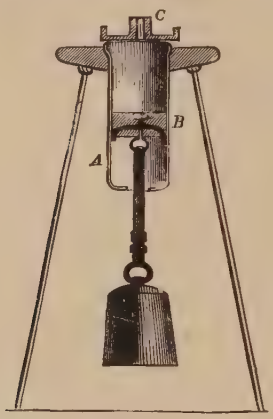


Fig. 179

Fig. 180

to expel the air; and the flask, after being removed from the source of heat, is tightly corked. It is then arranged as in

Fig. 181.

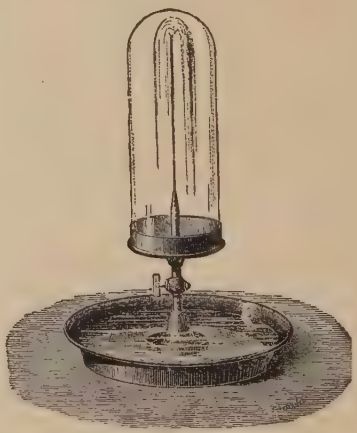


Fig. 182.

the figure, and cold water is poured over it. The tension of

the steam and its pressure on the water in the flask are thus reduced, and the liquid begins to boil again.

Questions. — Will water boil at the same temperature on the top of a mountain as at its base? Why? How would the boiling-point be affected at the bottom of a deep mine? Why?

Fig. 183.

Page 114. — The effect of *evaporation* in reducing the temperature, or rendering heat latent, may be shown by the experiment represented in Figure 184, which requires only such apparatus as is readily extemporized. A little water is put in a test-tube, which is placed in a wineglass of ether, and a current of air blown through the ether by means of the bellows. The water will be frozen in a very short time.

Fig. 184.

Page 145.—The use of the pith ball to show the presence of electricity naturally suggests its use in the *pith-ball electrometer* (Figure 185), which the teacher can easily make, if it is not among his apparatus. The wooden stem *C* is mounted in a

metal socket, by which it can be attached to the conductor whose electrification is to be measured. The pith ball, fixed to a straw stem *A*, is hung on a pivot at the centre of the graduated arc *B*. The number of degrees over which the

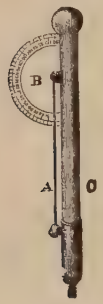


Fig. 185.

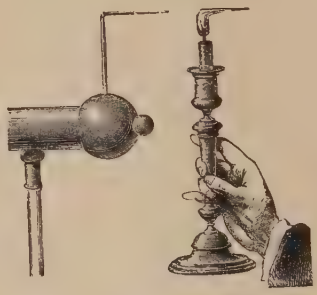


Fig. 186.

straw passes affords a rough measurement of the strength of the electrification.

Page 154. — In connection with the *silent discharge*, as illustrated in Figure 140, the "electric wind," caused by the charging of the molecules of air in front of the point, and their consequent repulsion, may be shown (Figure 186). The "electric mill" (Figure 187), which is driven by the reaction of the repelled molecules upon the point, may also be introduced here.

Fig. 187.

The *Leyden Jar* (Figure 188) serves as a striking illustration of *electrical induction.* When the inner coating is charged positively from the prime conductor of the electrical machine, the outer coating becomes charged negatively by induction. The outer coating, like the rubber of the machine (147), must be connected with the earth.

The *spark discharge* is well illustrated by discharging the jar by means of the "discharging rod" (Figure 189). The jar may be discharged *gradually* and *silently* by means of a small

metallic ball suspended by a silk thread, so as to swing between the rod from which it is hung and the ball of the jar (Figure 190). The rod must be connected by a strip of tin-foil

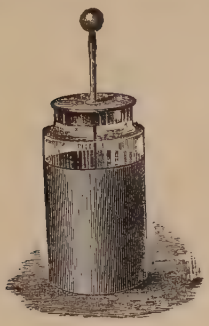


Fig. 188.

Fig. 189.

at its base (or by some other conductor) with the outer coating of the jar. The two bells shown in the figure are not necessary to the experiment, but add to its effect by their alternate ringing.

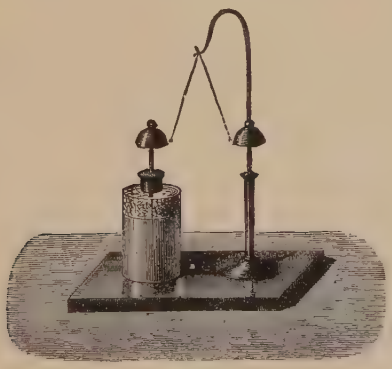


Fig. 190.

The *spark discharge* is also prettily illustrated by the "spangled pane" (Figure 191). A long strip of tin-foil is pasted in parallel lines, connected at alternate ends, between a knob at

the top and one at the bottom of the pane. A design is then traced on the page by means of a sharp point which cuts through the tin-foil. A discharge of electricity between the knobs brings out the pattern in lines of light, a spark being produced wherever the foil has been cut. The rod or wire from one of the knobs should not quite touch the discharging rod of the electrical machine. An interval of half an inch or so should be left for sparks to pass.

Fig. 191.

Many forms of this apparatus are made; but in all, the light is produced by the passage of electricity *through the air* (151) from one piece of tin-foil to another. Simple devices of the kind can be made with trifling labor and expense by the teacher.

NOTE. — Questions suggested by the experiments (of which a slight sample is given on p. 184 above) will readily occur to the teacher. Experiments always interest and amuse the pupil; but if he is not required to note and explain what is done, and how it illustrates phenomena not mentioned in the book, the exhibition will be about as profitable to him as a display of fireworks, or a dance of puppets on a hand-organ.

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